FINAL REPORT

LAKE OF THE WOODS FEASIBILITY STUDY

Submitted To:

LAKE OF THE WOODS
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December 1991

EXECUTIVE SUMMARY

International Science & Technology, Inc. (IS&T) has provided technical services to the Lake of the Woods Homeowners Association in conducting a Feasibility/Design Study of Lake of the Woods, Marshall County, Indiana. Due to the acquisition of most of the assets and all of the staff of IS&T by Dynamac Corporation, this report is being produced by Dynamac. The study was funded through the Indiana Department of Natural Resources Lake Enhancement Program (LEP).

The objectives of the Feasibility Study were three-fold:

- Assess the current condition of the lake and establish a baseline against which future changes can be measured.
- Identify potential threats to the well-being of the lake.
- Recommend lake and/or watershed management practices that minimize such threats.
- Update and add to information contained in the 1982 Clean Lakes Feasibility Study.

To meet these objectives, four separate phases of the study were necessary. First, all relevant background information, including maps, previously collected water chemistry data, copies of correspondence, and biological data, were collected and reviewed. This information was critical to understand the current status of knowledge on the lake. Second, lake surveys were conducted to collect data on water quality, abundance of algae, sediment chemistry, and water depths. Third, a watershed survey was conducted. This involved compilation of land use information for a land use map of the entire watershed. In addition, the watershed survey involved the application of computer models that predicted sediment and nutrient transport from the watershed, average in-lake phosphorus concentration, and annual phosphorus export from the watershed. The land use map and computer model results will be important tools for controlling and reducing the influx of nutrients to Lake of the Woods, and for identifying key problem areas. The fourth phase of the study involved the analysis of all data that had been collected, and development of recommendations that would have the greatest probability of improving the quality of this resource.

Management strategies recommended in this report are based on the most current understanding of the relationship between water quality and non-point source pollutants, i.e., those pollutants coming from diffuse sources in the watershed. The most effective long-term strategy for improving the quality of the lake is to reduce these inputs through the application of best management practices (BMPs) in the watershed. The Marshall County Soil and Water Conservation District and the Soil Conservation Service have already made significant progress in both education and implementation of agricultural BMPs. The results of the AGNPS modeling completed during this project can be used to target BMPs at key problem areas, i.e., those areas contributing relatively greater quantities of sediment and nutrients to the lake. To reduce the in-lake phosphorus concentration, and to quickly improve the trophic status of the lake, a one time alum application is recommended. This a technique that will greatly reduce the water column phosphorus concentration, and, more importantly, inhibit the transfer of phosphorus from the lake sediments for a long period of time, i.e., five to 10 years. The continually increasing amount of agricultural lands in Marshall County that are under some form of reduced tillage will greatly enhance this treatment. Funding for BMP implementation and in-lake restoration may be obtained through the LEP Lake Watershed Land Treatment Program, and/or through a U.S. EPA Clean Lakes Program Phase II Project.

Much of the information contained in this report is of a technical nature, and, like a report in any scientific field, may contain unfamiliar terms and information. An effort has been made to reduce the complexity of the report wherever possible, because it is intended to serve all those concerned about the future of Lake of the Woods. To clarify one concept that underlies the very nature of this study and the problems seen in the lake, a definition of eutrophication is in order. This term describes the natural aging process of lakes, in which the lake is gradually filled with marsh vegetation, then becomes a swale, and eventually a wooded area. This may take hundreds or even thousands of years, depending on the physical characteristics of the lake and the degree of man's intervention in the process.

Like many lakes that have agricultural watersheds, eutrophication of Lake of the Woods has been accelerated due to the addition of vital plant nutrients in runoff. Under normal conditions, these nutrients, primarily nitrogen and phosphorus, are in short supply, and come mainly from biological sources. Decaying plants and animals, weathering of watershed soils, and atmospheric inputs are the major natural sources of lake nutrients. The nature of the soils in the area and on the lake bottom is an important factor. The relatively deep soils of the midwest are characteristically rich in nutrients. The lakes in this area of the country are naturally more productive than areas with shallow soils, and rocky lake bottoms. Addition of nutrients from the watershed to Lake of the Woods has been in excess of the quantities normally present in the lake. A decrease in clarity, absence of dissolved oxygen in the deeper areas, and abundance of blue-green algae are all evidence of the effects of nutrient enrichment. This study documented these and other problems in the lake and watershed.

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SECTION 1. INTRODUCTION

This report presents the results of a Feasibility Study conducted on Lake of the Woods by International Science & Technology, Inc. (IS&T) for the Lake of the Woods Property Owners Association. The project was performed and funded under the provision of the State of Indiana "T by 2000" Lake Enhancement Program (LEP). The LEP was established to ensure the continued viability of Indiana's lakes by controlling sediment related problems, primarily erosion and nutrient enrichment. LEP Feasibility Study objectives are to characterize the lake and surrounding watershed, identify water quality related problems, present alternative solutions, and recommend the most appropriate solutions. The ultimate objective of the program is to restore the well-being of the lakes through development of specific plans of action for restoration (Design Phase) and the installation of the required control measures as appropriate (Construction Phase or Land Treatment Program).

1.1 LAKE OF THE WOODS

Located in Marshall County, Indiana, approximately four miles southwest of the town of Bremen, Lake of the Woods is a glacially formed kettle lake with a surface area of 416 acres, a maximum depth of 47.9 feet and a mean depth of 15.7 feet (Figure 1) (Senft and Roberts, 1982). The lake bottom consists of sand and muck (IDNR, 1987). The physical characteristics of the lake are summarized in Table 1.

Table 1. Physical characteristics of Lake of the Woods.

	LAKE OF THE WOODS	
Surface Area (acres)[1]	416	
Watershed Area (acres)	6,054	
Maximum Depth (ft)	47.9	
Mean Depth (ft)	15.7	
	1975	1987
IDEM[1] - Eutrophication Index Number	42	48
Trophic Class	Two	

[1] Data from Indiana Lake Classification System and Management Plan, Indiana Department of Environmental Management, 1986, and subsequent IDEM lake study.

All other data contained in Diagnostic Feasibility Study of Lake of the Woods, Marshall County, IN, 1982.

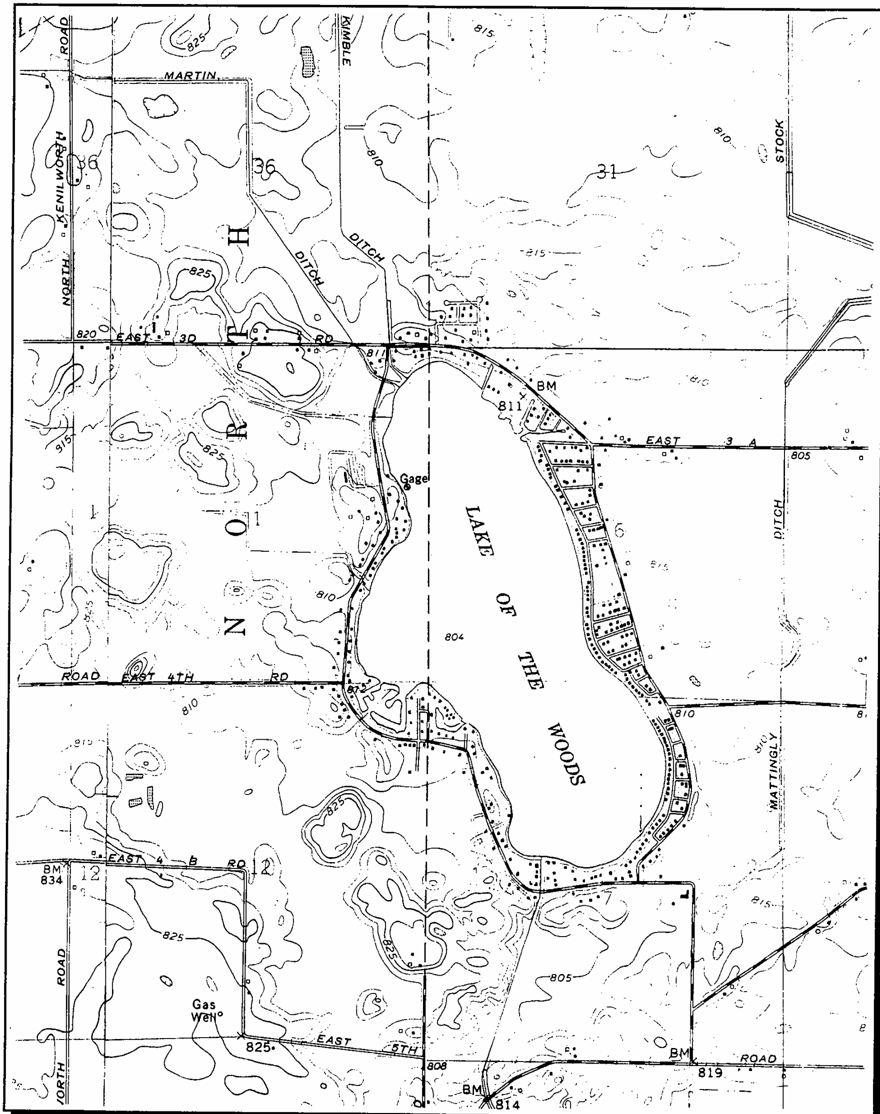

Figure 1. A portion of the USGS Bremen and La Paz quadrangles showing the location of Lake of the Woods.

The Lake of the Woods watershed consists of 6,054 acres of predominantly agricultural land. Corn, soybeans, and small grains are the principle crops grown. The two major tributaries to the lake, Walt Kimble Ditch and Martin Ditch, drain into the northern part of the lake. Three intermittent tributaries enter on the western shore, and a short canal (approximately 400 feet) drains into the northeastern shore. The lake outlet, at the southern end, is controlled by a fixed-crest concrete sill structure equipped with a movable gate (USGS, 1985). Lake of the Woods discharges into Isaac Sells Ditch which flows into the Yellow River.

With the exception of a small portion of the north-western shore, the Lake of the Woods shoreline is heavily developed with residential housing. All of the residences are currently on septic systems. The eastern shore residences are primarily in low lying areas, and the soils are often saturated following rains (Marshall County Sanitarian, pers. comm., 1990).

Geologically, the Lake of the Woods watershed is composed of Devonian age bedrock materials, largely limestone, dolomite, and black shale. Unconsolidated deposits consist of glacial till. The glacially formed lake was a result of the advance and retreat of the Saginaw and Erie lobes of the main glacier extending southwest from the Lake Erie and Saginaw Bay Basin during the most recent period of glaciation (14,000 to 22,000 years ago). The moraine topography, with interspersed bogs, lakes, and glacial drainage troughs and plains, is evidence of the glacier's effect on this portion of northern Indiana (Clark, 1980).

The soils surrounding Lake of the Woods have been described by the Soil Conservation Service (SCS) as deep, nearly level, and poorly drained. The two major soil associations found in this area are the Rensselaer-Whitaker and the Houghton-Adrian-Palms Associations (USDA, 1980).

The Rensselaer-Whitaker Association occurs in lands surrounding the majority of Lake of the Woods. This association is characterized by swales, and is commonly found on nearly level or depressional outwash plains, lake plains, and terraces.

The Houghton-Adrian-Palms Association is found along the southern lake shore, and in the near western portion of the watershed. This association is characterized by depressional topography, and is commonly found in bogs and on old glacial lakebeds.

1.2 NATURE OF THE PROBLEM

Accelerated eutrophication of Lake of the Woods, due primarily to nutrient enrichment from agricultural runoff and septic system leaching, has resulted in deteriorating water quality and impaired use. The U.S. EPA Phase I Clean Lakes Study (Senft and Roberts, 1982) provided a comprehensive evaluation of the sources and magnitude of this problem. Although some improvements have been seen in both the lake and watershed since completion of the Phase I study in 1982 (i.e., decreased total phosphorus concentrations and an increase in watershed BMPs), problems associated with nutrient enrichment remain.

Based on data collected by the Indiana State Board of Health (ISBH) in 1975, Lake of the Woods was given a BonHomme Eutrophication Index number (EI) of 42, as reported in the Indiana Lake Classification System and Management Plan (IDEM, 1986). This places the lake in the Class Two trophic category, which includes the majority of lakes in Indiana. Lakes in this trophic group are intermediate in terms of productivity, and frequently support extensive growths of macrophytes and/or algae. The data collected during the Phase I study in 1980-1981 showed no appreciable change in trophic status (Senft and Roberts, 1982). Lake of the Woods was surveyed again by the Indiana Department of Environmental Management (IDEM) on 29 July 1987. The EI value calculated from the 1987 data was 48, an increase of six points over the value obtained 12 years earlier. Although the lake remained a Class Two lake (EI values of 26-50), a decrease in overall quality was apparent.

Based on the cluster analysis of the statewide lake survey data collected during the 1970's, as reported in the Indiana Lake Classification System and Management Plan (IDEM, 1986), Lake of the Woods was placed in the Lake Management Group VIIB. Management strategies for restoring lakes in this group focus on limiting nutrient inputs. Water quality problems within this group are usually not severe enough to warrant drastic restoration measures. Specific management strategies include phosphorus removal requirements for wastewater treatment plants in the drainage basin, septic system maintenance programs, protection of wetland areas, erosion control, and establishing buffer corridors for agricultural areas adjacent to the lake and tributary streams. Selected in-lake restoration techniques that may be used include sediment consolidation, nutrient inactivation, and dilution/flushing.

1.3 STUDY OBJECTIVES

The overall objective of the Lake of the Woods Feasibility Study was to assess the current conditions in the lake and watershed with respect to sedimentation and water quality, and develop mitigative strategies that would have the greatest probability of success in improving the overall quality of the lake.

Four phases of activity were required to meet this objective. First, relevant information on the lake and watershed (e.g., USGS topographic maps, aerial photographs of the lake and watershed, soils information, fisheries studies, hydrological data, natural areas information, and previous water quality data) was collected and reviewed. This information was used to understand the physical setting of the lake, and the current status of knowledge regarding sedimentation and water quality problems.

The second phase of the study involved the collection of field data from the lake and tributaries. Water samples and in-situ chemical and physical data were collected, and sediment characteristics and algal composition were determined. Additionally, bathymetric data were collected from the lake. These data provided the most recent evaluation of chemical, biological, and physical conditions in Lake of the Woods.

A watershed survey comprised the third phase of the project. Components of this survey included the identification of existing and drained wetlands in the watershed using National Wetland Inventory maps and soils information, an estimation of near-shore septic system contributions to nutrient loading, as well as an accurate description of current land use practices. Areas of excessive nutrient and sediment loading were identified using the Agricultural Non-Point Source Pollution (AGNPS) computer model developed by the U.S. Department of Agriculture. The watershed survey was critical in addressing problems at their source, and for developing the most appropriate mitigative strategies.

The final phase of the project was to develop appropriate recommendations to mitigate the problems observed in this study, and to update and add to information contained in the 1982 Feasibility Study (Senft and Roberts, 1982). This phase involved not only the identification of appropriate BMPs to address the critical sources of sediment and nutrients, but also the development of a long-term monitoring plan for the lake. The methods used in each phase of the project and the results of the study are presented in the following sections.

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SECTION 2. HISTORICAL DATA COLLECTION

The following section describes the historical data collected for this study. This information included previous land use practices, water quality data, fisheries studies, aquatic vegetation surveys, and a listing of significant natural areas and endangered species in the watershed. Several state and county agencies, as well as universities, were contacted in pursuit of this information. Table 2 presents a summary of the historical data obtained for Lake of the Woods.

Table 2. Lake of the Woods historical data summary.

DATE	AGENCY	DESCRIPTION
1964	IDNR	Lake Survey Report
1975	ISBH	Lake Survey Data
1977	IDNR	Fish Management Report
1979	IDNR	A Survey of Fish Harvest at Lake of the Woods, Marshall County: May 1 - September 10, 1978
1980	USDA - SCS	Soil Survey of Marshall County
1981	ISBH	Interoffice Memorandum re: Lake of the Woods Diagnostic Feasibility Study Interim Report
1982	IDNR	Fish Management Report
1982	U.S. EPA	Diagnostic Feasibility Study of Lake of the Woods
1984	IDNR	Evaluation of Tiger Muskellunge Stockings in Lake of the Woods
1985	USGS	Legal Description of Lake of the Woods and the Lake Level; List of Extreme Lake Levels 1945 - 1985
1986	IDNR	The Effects of a 14-Inch Size Limit on the Largemouth Bass Population at Lake of the Woods; Progress Report: 1986
1986	Marshall Co. Health Dept.	Bacteriological Survey
1987	IDNR	Fish Management Report
1987	IDEM	Lake Survey Data
1989	IDNR	The Effects of a 14-Inch Size Limit on the Largemouth Bass Population at Lake of the Woods; Final Report: 1989
1990	IDNR	Lake of the Woods Walleye Management Report
1990	USDA - SCS	Residue Tillage Transect Results - Marshall Co.
1990	CTIC	Conservation Tillage Practices in Marshall County (1984 through 1989).

2.1 LAND USE

Historically, the majority of the land in Marshall County has been utilized for agriculture, with approximately 81 percent of the county actively farmed. Corn, soybeans, and small grains are the major crops. Small truck farms and specialty crop farms (i.e., Christmas trees and orchard fruit) are also located throughout the county (USDA, 1980).

Data obtained from the Conservation Technology Information Center (CTIC) for 1984 through 1989 showed that corn was the dominant crop, followed by soybeans and small grains (such as wheat, rye, barley, oats, etc.). In 1984, conservation tillage practices were used on 34 percent of the active cropland, with the predominant type of conservation tillage being mulch-till. From 1984 through 1989, the percentage of active cropland on which conservation tillage practices were used increased from 34 percent to 58 percent. Mulch-till remained the preferred type of conservation tillage during this time period (CTIC, 1989).

Information obtained from the SCS for 1989 and 1990 corresponded with the CTIC information. Moldboard plowing was utilized on only 24 percent of the cropland in 1990, a decrease of 16 percent over 1989. Of the 185,000 acres of cropland surveyed in 1989 (93% of the total area planted) 80,000 (43%) was planted in corn and 62,500 acres in soy beans (34%). Farming practices designed to reduce sediment loss, and thus decrease sediment and nutrient concentrations in surface waters, were practiced on 70% of the acreage surveyed that was planted in corn. No-till agriculture was practiced on 6,000 acres (7.5%) of the corn acreage. Mulch-till farming was practiced on 50,000 acres, however, there was a great deal of variability in the amount of residue left on the fields, in many cases as little as 10%. For erodible soils, the Marshall County SWCD recommends a minimum of 30% residue to protect the fields from erosion and soil loss. Of the total soybean acreage, 5% was no-till, and approximately 37% was mulch-till agriculture. As with corn acreage, there was a great deal of variability in the amount of residue left on the fields.

2.2 WATER QUALITY

Tables 3 and 4 present a summary of the historical water quality data collected on Lake of the Woods and its tributaries. The location of the tributary sampling stations is denoted in Figure 2. Sources of this information include the ISBH, the IDEM, the IDNR, Marshall County Health Department and the U.S. EPA. Although there is little consistency among the parameters reported, there is a noticeable decrease in the average in-lake total phosphorus (TP) concentration between the years 1975 and 1987. A comparison of the Secchi disk transparency measurements taken in July 1975 and July 1987 shows an overall decrease in transparency.

Bacterial analyses, conducted in 1981, indicated that the lake received some bacterial contamination. This survey showed no large differences in bacterial counts among sample sites around the lake. However,

Table 3. Lake of the Woods historic water quality data.

DATE	LOCATION	SOURCE	TP mg/L	OP mg/L	NO_3 mg/L	NH_4 mg/L	TKN mg/L	Total Coliform #/100ml	Fecal Coliform #/100ml	Fecal Strep. #/100ml	Secchi (ft)
06/64	mid-lake	IDNR									3.8
07/75	mid-lake	ISBH	0.090	0.05	1.50	0.60	1.40				3.0
07/77	mid-lake	IDNR									2.0
01/81	mid-lake	USEPA									8.9
02/81	mid-lake	USEPA									1.6
03/81	mid-lake	USEPA									3.9
04/81	mid-lake	USEPA						260	20	70	
05/81	mid-lake	USEPA						1,000	10	140	
06/81	mid-lake	USEPA						15	10	140	
07/81	mid-lake	USEPA						20	7	430	
07/81	mid-lake	USEPA						40	9	860	
08/81	mid-lake	USEPA						75	5	280	
06/82	mid-lake	IDNR									4.5
05/86	Public Access - 15' offshore	Marshall Co. Health Dept.							350		
05/86	Gordy Beach - 25' offshore	Marshall Co. Health Dept.							60		
06/86	Public Access	Marshall Co. Health Dept.							30		
06/86	Boat Launch	Marshall Co. Health Dept.							30		
07/87	mid-lake	IDEM	0.042		0.45	0.88	1.92				2.5
1990	mid-lake	IDEM									2.4*

* Average secchi disk transparency from July and August 1990. Data collected under the Indiana Volunteer Lake Monitoring Program 1990.

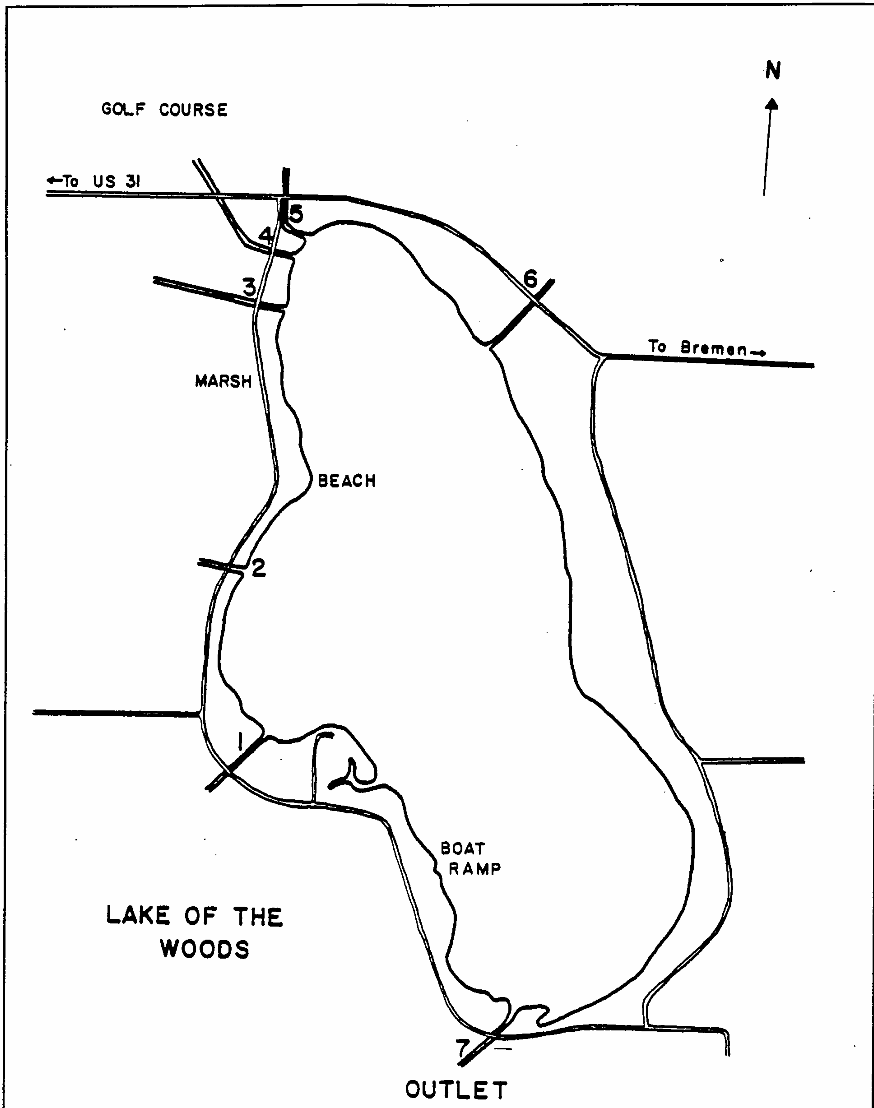

Figure 2. Lake of the Woods tributary sample stations utilized for the U.S. EPA Phase I Diagnostic Feasibility Study.

Table 4. Historic water quality data for Lake of the Woods tributaries.

DATE	LOCATION	SOURCE	Annual Average Flow-Weighted TP mg/L	Total Coliform #/100ml	Fecal Coliform #/100ml	Fecal Strep. #/100ml
04/81	Walt Kimble Ditch	USEPA		6,900	0	390
06/81	Walt Kimble Ditch	USEPA		150	400	2,500
07/81	Walt Kimble Ditch	USEPA		5,500	1,200	3,300
07/81	Walt Kimble Ditch	USEPA		1,500	590	4,000
08/81	Walt Kimble Ditch	USEPA		2,600	370	3,900
1981	Walt Kimble Ditch	USEPA	0.132			
04/81	Martin Ditch	USEPA		6,300	3,000	1,400
06/81	Martin Ditch	USEPA		2,000	2,400	2,000
07/81	Martin Ditch	USEPA		6,700	1,400	6,700
07/81	Martin Ditch	USEPA		5,200	5,400	54,800
08/81	Martin Ditch	USEPA		4,600	1,400	4,200
1981	Martin Ditch	USEPA	0.133			
04/81	LOW - 1	USEPA		410	3,100	350
06/81	LOW - 1	USEPA		3,100	2,400	2,400
07/81	LOW - 1	USEPA		3,200	990	2,800
07/81	LOW - 1	USEPA		440	630	4,900
08/81	LOW - 1	USEPA		47,000	1,300	2,100
1981	LOW - 1	USEPA	0.058			
04/81	LOW - 2	USEPA		690	110	770
06/81	LOW - 2	USEPA		700	510	810
07/81	LOW - 2	USEPA		4,300	880	2,900
07/81	LOW - 2	USEPA		400	390	1,700
08/81	LOW - 2	USEPA		1,500	450	1,400
1981	LOW - 2	USEPA	0.048			

Table 4. **Historic water quality data for Lake of the Woods tributaries (concluded).**

DATE	LOCATION	SOURCE	Annual Average Flow-Weighted TP mg/L	Total Coliform #/100ml	Fecal Coliform #/100ml	Fecal Strep. #/100ml
04/81	LOW - 3	USEPA		5,000	4,000	110
06/81	LOW - 3	USEPA		6,800	4,000	28,000
07/81	LOW - 3	USEPA		2,500	2,200	1,400
07/81	LOW - 3	USEPA		6,000	250	16,200
08/81	LOW - 3	USEPA		100	220	1,600
1981	LOW - 3	USEPA	0.179			
04/81	LOW - 6	USEPA		830	180	60
06/81	LOW - 6	USEPA		2,800	1,600	2,700
07/81	LOW - 6	USEPA		1,900	780	6,200
07/81	LOW - 6	USEPA		1,200	660	1,400
08/81	LOW - 6	USEPA		1,900	140	1,200
1981	LOW - 6	USEPA	0.070			
04/81	outlet	USEPA		3,800	130	1,000
06/81	outlet	USEPA		150	250	390
07/81	outlet	USEPA		70	280	230
07/81	outlet	USEPA		1,600	790	2,400
08/81	outlet	USEPA		40	15	200
1981	outlet	USEPA	0.053			

shoreline samples generally had bacterial counts higher than the in-lake stations, which may indicate septic system leaching around the entire lake as opposed to an isolated input from a single tributary or home (Senft and Roberts, 1982).

The 1981 bacterial analyses of the tributaries (Table 4) indicates fecal coliform levels in excess of the IDEM standard for whole body contact recreation (i.e., 400 colonies per 100 ml) throughout most of the summer. No pattern of contamination could be determined, however Senft and Roberts (1982) postulated that the contamination occurred from human as well as animal wastes. The flow weighted yearly average TP in the tributaries of Lake of the Woods indicates that tributary LOW-#3 contributed the most phosphorus to the lake in 1981. This tributary had an average annual weighted TP concentration of 0.179 mg/L. The second and third highest TP contributions, during this study period, came from Martin and Walt Kimble Ditches. These tributaries had weighted TP concentrations of 0.133 mg/L and 0.132 mg/L, respectively. Tributaries LOW-#1, LOW-#2, and LOW-#6 all contributed significantly less TP to the lake during the study period.

In 1986, bacteriological surveys were conducted on Lake of the Woods by the Marshall County Health Department in response to a potential septic system overflow into the lake. The majority of the samples were collected from an area located on the southwest side of the lake, near the Carlton Apartments. A septic system tile from the apartments emptied directly into an adjacent ditch, which then flowed under East 4th Road and into the lake. Samples were collected from the mouth of the ditch in March, April and May, and from the drainage ditch between the septic tile outflow and East 4th Road in April and May of 1986. Table 5 documents the results of this survey.

Table 5. Bacteriological survey of the southwest portion of Lake of the Woods.

SITE	DATE	FECAL COLIFORM #/100 ml	FECAL STREPTOCOCCUS #/100 ml
Ditch discharge to lake	03/24/86	88,000	nda
Ditch discharge to lake	03/24/86	47,000	nda
Ditch between tile and road	04/16/86	2,400	2,900
Ditch discharge to lake	04/16/86	< 10	< 10
Ditch between tile and road	05/13/86	1,600	340
Ditch discharge to lake	05/13/86	< 10	90

In addition to the data shown in Tables 3 through 5, IDEM collected and analyzed fish tissue and lake sediment samples in 1987. Fish tissues from four fish species; gizzard shad, large mouth bass, white sucker and bluegill were analyzed for the following parameters:

- Percent fat
- Pesticides
- PCBs
- Metals
- Acid extractable organics
- Base neutral extractable organics
- Volatile organics.

Based on discussion with IDEM, the results of these analyses were all below the "action limits", or guidelines established by the Food and Drug Administration for fish consumption.

In addition to the fish tissue analyses, the 1987 monitoring by IDEM included collection and analysis of sediment samples at Lake of the Woods. Two composites, each made up of three grab samples collected at the north end and at the south end of the lake, were analyzed for the same parameters listed above, with the exception that percent solids was substituted for percent fat. Levels of all of the parameters analyzed in the sediment samples were below the background level determined by IDEM from a statewide study of 83 lake and stream sites. Further information on both the sediment and fish tissue analyses for Lake of the Woods can be obtained from Lee Bridges at IDEM's Bradbury office in Indianapolis. Mr. Bridges can be reached at (317) 243-5030.

2.3 FISHERIES SURVEYS

IDNR has conducted numerous fisheries surveys on Lake of the Woods since 1964. Fish population surveys reviewed as a component of the historical data collection effort included those conducted in 1964, 1977, 1982, and 1987. Additionally, a creel survey conducted in 1978, largemouth bass size limit studies conducted in 1986 and 1989, and tiger muskellunge and walleye stocking reports from 1984 and 1990 respectively, were also reviewed. Species documented in the fish population survey reports and their relative abundance are listed in Table 6. Table 7 documents the stocking efforts at Lake of the Woods. The 1977 and 1987 survey reports also included a list of common aquatic plants found in Lake of the Woods at the time of the surveys.

The 1964 fish population survey found that white crappie (Pomoxis annularis) and yellow perch (Perca flavescens) comprised approximately 75% of the entire fish population. Both species are considered predators after attaining a larger size (i.e., 6 and 8 inches, respectively). The majority of these two species collected were smaller than the above ranges however, and were classified as forage fish. Due to competition for food and space among the panfish species, a deterioration in the fishery was expected to occur. Management recommendations included a re-survey to be conducted in 1968 to document any fishery deterioration, with more specific management recommendations to be made at that time.

Table 6. Fish species and relative abundance in Lake of the Woods. (IDNR Fish Management Reports)

COMMON NAME	SCIENTIFIC NAME	1964	1977	1982	1987
White Crappie	Pomoxis annularis	48.5%	24.8%	38.9%	4.5%
Yellow Perch	Perca flavescens	26.2%	19.3%	6.7%	8.5%
Bluegill	Lepomis macrochirus	11.4%	3.1%	20.5%	8.3%
Golden Shiner	Notemigonus crysoleucas	3.9%	4.5%	3.5%	1.5%
Pumpkinseed	Lepomis gibbosus	3.5%	2.4%	1.7%	3.7%
Carp	Cyprinus carpio	2.6%	3.4%	1.5%	1.0%
Largemouth Bass	Micropterus salmoides	1.6%	4.1%	0.3%	3.6%
Black Crappie	Pomoxis nigromaculatus	0.9%	22.1%	18.0%	3.8%
Brown Bullhead	Ictalurus nebulosus	0.4%	3.1%	0.5%	***
Yellow Bullhead	Ictalurus natalis	0.2%	0.3%	0.1%	0.1%
Longnose Gar	Lepisosteus osseus	0.3%	***	***	***
Spotfin Shiner	Notropis spilopterus	0.2%	***	***	***
White Sucker	Catostomus commersoni	0.0%	11.4%	3.8%	3.1%
Brook Silverside	Labidesthes sicculus	0.0%	***	0.0%	abundant
Green Sunfish	Lepomis cyanellus	0.0%	***	0.1%	***
Grass Pickerel	Esox americanus	0.0%	***	***	***
Madtom	Notorus spp.	0.0%	***	***	***
Bigmouth Buffalo	Ictiobus cyprinellus	0.0%	***	0.1%	0.2%
Spotted Gar	Lepisosteus oculatus	0.0%	***	0.1%	***
Quillback	Carpiodes cyprinus	0.0%	***	***	0.5%
Bowfin	Amia calva	0.0%	***	0.2%	***
Gizzard Shad	Dorosoma cepedianum	***	1.4%	0.3%	58.5%
Channel Catfish	Ictalurus punctatus	***	***	2.7%	1.1%
Black Bullhead	Ictalurus melas	***	***	0.6%	***
Tiger Muskellunge	Esox masquinongy x E. lucius	***	***	0.2%	0.4%
Warmouth	Lepomis gulosus	***	***	0.2%	0.3%
Northern Pike	Esox lucius	***	***	0.1%	***
Lake Chubsucker	Erimyson sucetta	***	***	0.1%	***
Fathead Minnow	Pimephales promelas	***	***	present	***
Bluntnose Minnow	Pimephales notatus	***	***	***	0.8%
Spotted Sucker	Minytrema melanops	***	***	***	0.1%

* 0.0% denotes less than 0.1% of the population.
*** species not found.

The fishery survey conducted in July 1977 found both white crappie and black crappie (Pomoxis nigromaculatus) to comprise almost 47% of the fish population. The overall percentage of game fish found in the lake was 76.9%, a decrease since the 1964 survey. The number of largemouth bass (Micropterus salmoides) and bluegill (Lepomis macrochirus) collected was noted to be following a pattern of decline. Additionally, the number of gizzard shad (Dorosoma cepedianum) was drastically reduced

Table 7. Historical fish stocking records for Lake of the Woods. (IDNR Fish Management Reports)

SPECIES	DATE	NUMBER STOCKED	SIZE (inches)
Tiger Muskellunge	July 1978	1,780	4.0-6.0
Tiger Muskellunge	Sept. 1980	2,100	6.0-7.5
Tiger Muskellunge	July 1981	4,000	5.0
Tiger Muskellunge	Sept. 1983	4,160	8.3
Tiger Muskellunge	Sept. 1985	3,375	8.4-10.4
Total Tiger Muskellunge Stocked:		15,415	
Channel Catfish	Nov. 1980	4,284	3.5-16.0
Channel Catfish	Oct. 1987	2,080	6.9-10.8
Total Channel Catfish Stocked:		6,364	
Walleye	July 1990	78,902	1.5-1.9
Total Walleye Stocked:		78,902	

from the previous years' survey. This population reduction was attributed to a fish kill that occurred during the severe winter of 1976-1977. The 1977 survey recommendations included conducting a creel survey in 1978 to obtain more accurate information about species, numbers, and size of the fish harvested from Lake of the Woods. To gain more information specific to the bluegill population, trapping was recommended for the late May to mid-June time period in 1978. If the results of the recommended creel survey and trapping exercises indicated that fish harvest was low and the bluegill population small, a total renovation of the fishery would be recommended for implementation in 1979.

The 1978 creel survey at Lake of the Woods was implemented between 1 May and 10 September. The results of this survey indicated that fishing was marginal, although the catch rate was average for northern Indiana lakes. The lake was found to support a good crappie and yellow perch fishery, although very few large fish were harvested. The bluegill harvest was low and substantiated the low numbers of bluegill found during previous surveys. Additionally, very few largemouth bass were noted during the survey, however approximately 45% of those caught were of a larger size (i.e., 14 inches or longer). The fish management recommendations, based on the results of the creel survey, included monitoring the growth of the tiger muskellunge that had recently (July 1978) been stocked into the lake. Additionally, a channel catfish stocking program was recommended, with a second creel survey to be conducted in 1980 to measure the contribution of tiger muskies and catfish to the overall fish harvest.

In 1982, another fishery survey was conducted to determine the status of the fish population and to evaluate the tiger muskellunge stockings in Lake of the Woods. This survey found that white crappie was the most abundant species present (39% of the population), with bluegill ranking second in relative abundance (21%). Channel catfish (Ictalurus punctatus), first stocked in 1980, had become common and were providing many fishing opportunities. However, the tiger muskellunge stockings in 1978, 1980, and 1981 had failed to produce a trophy fishery for this species. Fish management recommendations included stocking 10-inch tiger muskellunge in 1983, and 8-inch Channel Catfish in 1984 to improve the quality of the overall fishery.

In 1984, a Tiger Muskellunge Awards Program was conducted to determine the number of legal size tiger muskies harvested, the number released, the size of those harvested, and to increase public awareness of tiger muskie fishing opportunities at Lake of the Woods. Fishermen were asked to register their tiger muskellunge catch from the lake at one of two recording stations. In return, the fishermen were to be given an embroidered tiger muskie patch, and the person with the most fish registered would be awarded a certificate acknowledging this achievement. During the seven month period of the Awards Program, only one tiger muskie was registered. An evaluation of tiger muskellunge stockings, based on the Awards Program, indicated that, to date, the stocking of over 12,000 tiger muskies had failed to produce even a small trophy fishery for this species. Gill netting efforts and electrofishing in August 1984 indicated that some of the tiger muskies stocked in 1983 had survived, although survival of the earlier stocked fish had been poor. The 1984 tiger muskellunge evaluation report recommended stocking advanced fingerlings in September 1985.

The results of the 1987 fishery survey indicated that gizzard shad dominated the survey catch, comprising 59% of the sample. Yellow perch were a distant second in abundance (9%). The fish population of Lake of the Woods, between 1982 and 1987, showed a drastic change. In 1982, the population was dominated by popular gamefish, such as white crappie, bluegill, and black crappie. The 1987 fish population was dominated by the nongame gizzard shad, and black crappie and bluegill had severely declined. Gizzard shad had been abundant in the lake prior to the winterkill of 1976-77. The shad had remained rare or absent from fisheries surveys conducted between 1977 and 1984, but had apparently returned to the high levels found in the mid 1970's by the time of the 1987 fishery survey. Fish management recommendations included a re-survey of the fishery after the proposed sewage system installation was complete and operational. The information collected during this re-survey would be used with previous survey data to determine the difference, if any, in fish populations before and after the sewage system was operational.

A study to determine the effectiveness of a 14-inch minimum size limit for largemouth bass was initiated at seven northern Indiana lakes, including Lake of the Woods, in 1984. The results of a preliminary evaluation survey, in 1986, indicated that the largemouth bass population had increased by 67% since 1985. Proportional stock densities (i.e., the percentage of bass measuring 8 inches and larger that were also 12 inches and larger) had also increased since 1985. During the six years of this project (1984-1989), several overall improvements were noted in the bass population at Lake of the Woods. The population increased from an estimated 391 fish in 1985 to a population of 3,148 fish in 1989. Additionally, the number of bass per acre of lake, as well as the pounds of bass per acre, increased steadily during this time period. Young-of-the-year bass were also collected at a greater rate following implementation of the size limit. The overall conclusion, based on six years of observation, was that the 14-inch size limit had a positive effect on the Lake of the Woods bass population.

In July 1990, 78,902 walleye fingerlings were stocked at Lake of the Woods. The fish averaged 1.7 inches long. In October 1990, a survey was conducted to monitor the growth and survival of this walleye stocking. The results of the survey indicated that walleye growth and survival were good. It was recommended that additional fingerlings be stocked in 1991 to develop a challenging walleye fishery in this lake.

2.4 AQUATIC MACROPHYTES

Aquatic macrophyte surveys conducted by the IDNR during the fishery surveys of 1977 and 1987 identified eight (8) plant species in Lake of the Woods. The plant species identified during these surveys are presented in Table 8. Comments recorded during these surveys indicated that no chemical aquatic plant control program had been recommended by the IDNR.

Table 8. Historic data on aquatic plant species found in Lake of the Woods. (IDNR Fish Management Reports)

COMMON NAME	SCIENTIFIC NAME	1977	1987
Cattail	Typha spp.	X	X
Water Lily	Nymphaea tuberosa	X	X
Spatterdock	Nuphar advena	X	X
Bulrush	Scirpus spp.	X	X
Arrowhead	Sagittaria latifolia	X	X
Coontail	Ceratophyllum demersum	X	X
Water Milfoil	Myriophyllum spp.	X	X
Chara	Chara spp.	X	X

2.5 SIGNIFICANT NATURAL AREAS AND ENDANGERED AND THREATENED SPECIES

Significant natural areas and endangered and threatened species in the Lake of the Woods watershed were identified by the IDNR Division of Nature Preserves. The Division of Nature Preserves has a database of information pertaining to these significant areas and species and can identify their locations by USGS quadrangle map. Only one historical entry was identified within the Lake of the Woods watershed boundary. That entry was Broadwing Sedge (scientific name: Carex alata). This species is listed as rare within the state, and was collected in 1922 by Charles Deam along the sandy border on the east side of the lake. There are no other state listed species, nature preserves, significant natural areas or natural features listed within this area (H. Huffman, pers. comm., 1991).

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SECTION 3. LAKE AND WATERSHED SURVEY METHODS

This section of the report describes the methods used to complete the Lake of the Woods Feasibility Study. The data collection efforts for this project were divided into two sub-tasks: (1) a lake survey, and (2) a watershed survey.

3.1 LAKE SURVEY

IS&T personnel conducted a survey of Lake of the Woods during the late summer and fall of 1990, and early spring 1991, to collect the information required for a detailed assessment of the current conditions in the lake and watershed. Samples were collected to analyze lake and tributary water quality, phytoplankton diversity and abundance, and sediment nutrient concentrations. A bathymetric survey of the lake was also conducted. The methods used for sample collection and other components of the field survey are described below.

3.1.1 In-situ Measurements

In-situ water quality, water samples and phytoplankton were collected on 6 September 1990 at one in-lake station identified as one of the deepest parts of the lake (Figure 3). In-situ profile measurements of temperature, dissolved oxygen, pH, and conductivity were made using a Hydrolab "Surveyor II" Environmental Data System. Measurements were recorded at the surface, at a depth of three feet, at one foot increments to a depth of 10 feet, at two foot increments to a depth of 20 feet, and at five foot increments to the lake bottom. Secchi disk transparency was measured on the shaded side of the boat. The Secchi disk was lowered until it disappeared, and then raised until it reappeared. The average of these two depths was reported as the Secchi disk depth. Percent light transmission was recorded at the surface, three feet, five feet, and at two foot increments to a depth of 9 feet, using a Martek Model XMS transmissometer. This instrument was calibrated, on the lake, prior to use.

3.1.2 Chemical Measurements

Water samples were collected from a depth of 3 feet below the water surface, and from 3 feet above the lake bottom (40 feet) using a 6 liter (6.6 quart) vertical Van Dorn water sampler. Samples were collected on September 6, 1990. All in-lake water samples were collected at the same location as the in-situ data. Samples for nutrient analysis were poured directly from the Van Dorn into clean, laboratory prepared containers. Aliquots collected for fecal coliform, total coliform, fecal streptococci, and E. coli bacterial analysis were poured into sterilized, laboratory prepared containers. Separate aliquots were also collected for chlorophyll a analysis. All samples were immediately placed in coolers and chilled to approximately $4^{o}C$ prior to shipment to the analytical laboratory. The samples were received, by the laboratory, within 24-hours of collection. Table 9 lists the analytes measured in the water samples and the methods used

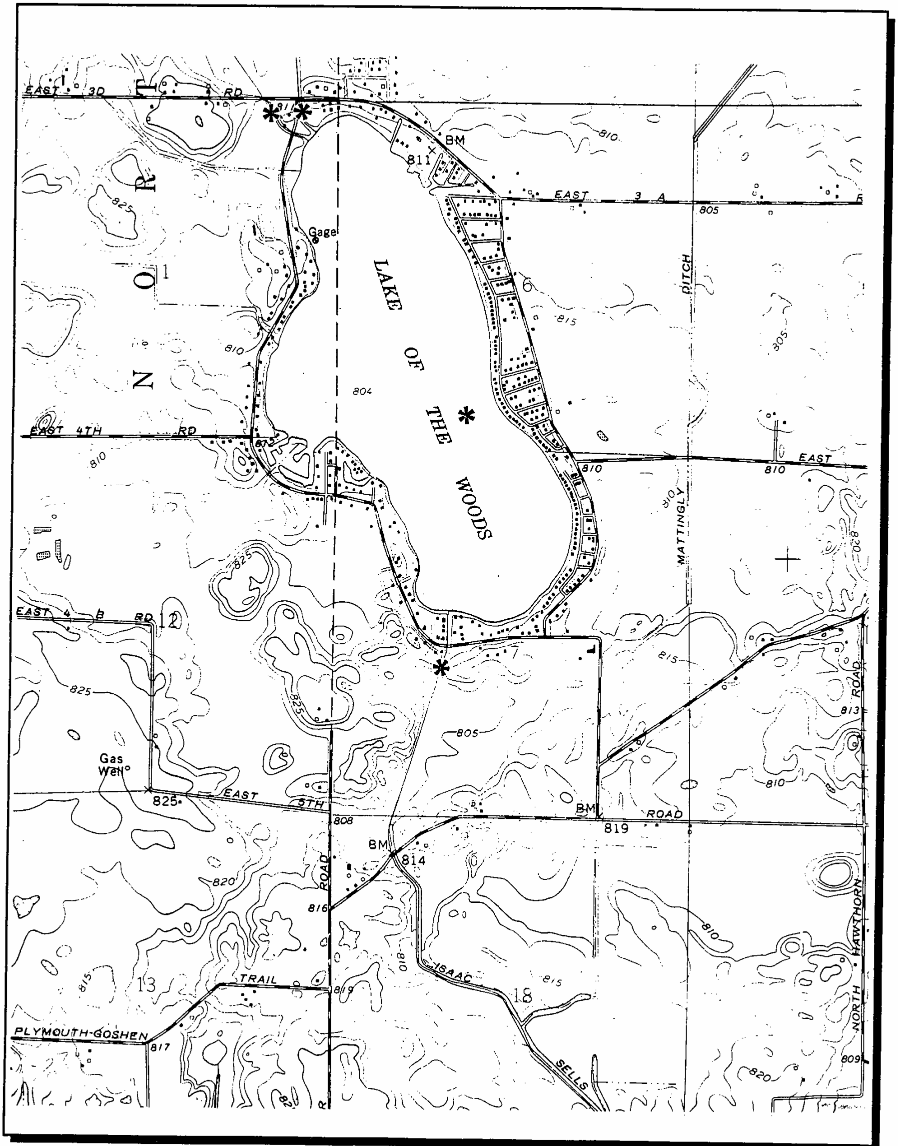

Figure 3. In-lake and tributary sampling locations.

Table 9. **Chemical parameters and analytical methods used in evaluating the Lake of the Woods water and sediment samples.**

PARAMETER	PROCEDURE	REF.	CITATION
Water Samples:			
Total Phosphorus, mg/L as P	Digestion, Ammonium Molybdate	1	424C.E
Ortho-Phosphorus, mg/L as P	Ammonium Molybdate Colm.	2	365.1
Nitrate Nitrogen, mg/L as N	Hydrazine, Colorimetric	2	353.1, 354.1
Ammonia Nitrogen, mg/L as N	Automated Phenate Colorimetric	1	350.1
Total Kjeldahl Nitrogen, mg/L as N	Digest, Distill, Phenate	1	420A, 417B
Organic Nitrogen, mg/L as N	Digest, Distill, Colm.	1	420A, 417B
Total Suspended Solids, mg/L	Gravimetric, 103-105°C	1	209C
Chlorophyll a, µg/L	Acetone extraction	1	
Escherichia coli Bacteria, #/100 ml	Membrane Filtration	4	M1103.1
Fecal Streptococci Bact., #/100 ml	Membrane Filtration	3	111.D.2
Fecal Coliform Bacteria, #/100 ml	Direct Membrane Filtration	3	111.C.2
Total Coliform, #/100 ml	Membrane Filtration	3	111.B.2
Sediment Sample:			
Total Phosphorus, mg/kg as P	Digestion, Ammonium Molybdate	1	424C.E
Total Kjeldahl Nitrogen, mg/kg as N	Digest. Distill, Phenate	1	420A, 417B
Percent Total Solids, g/100 g	Gravimetric, 103-105°C	1	209F

(1) Standard Methods for the Examination of Water and Wastewater, 16th Ed., 1985. American Public Health Assoc., 1015 Fifteenth St. NW, Washington, DC.
(2) Methods for Chemical Analysis of Water and Wastes. USEPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA-600/7-79-0-20. Revised March 1983.
(3) Microbial Methods for Monitoring the Environment. USEPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA-600/8-78-017. December 1978.
(4) Test Methods for Escherichia coli and Enterococci in Water by Membrane Filter Procedure. USEPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA-600/4-85-076.

to conduct the analyses. Quality assurance for lake water quality analyses consisted of blank (deionized water) and split sample analyses in the laboratory, and analysis of field duplicate samples. The latter were from another lake sampled by the IS&T field crew on the same day, and included in the same batch of samples sent to the analytical laboratory.

Water samples were also collected from Martin and Walt Kimble Ditches, and the lake outlet on Wednesday, April 3, 1991. Although close to one inch of rain (0.89 inches recorded at the South Bend airport) fell during the preceding week, and a storm was predicted on that day, no measurable precipitation was recorded on April 3. A total of 0.46 inches was recorded on the following day. Despite the lack of actual precipitation, observations from local residents indicated that flow in the major tributaries to the lake at the time of sampling was elevated, and typical of conditions during periods of frequent spring rains. Figure 3 shows the location of the tributary sampling stations. One grab sample was collected from each stream at mid-channel. Quality assurance samples, consisting of duplicate water and bacteria samples, were collected at the same time. The tributary samples were placed on ice and delivered to the analytical laboratory within 6 hours of collection. The samples were analyzed for total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3-N), total suspended solids (TSS), fecal coliform, and E. coli bacteria. Samples for fecal coliform and E. coli bacterial analyses were also collected from two separate ditches on the eastern side of the lake, one along Chicago Road, and the other near Abbott Street.

In addition to water sample collection, stream cross-sectional area and velocity were measured at the two tributary and outlet stations. The cross-sectional area was determined from depth soundings of the stream, made in a transect from shore to shore, at the point where the velocity measurements were made. Velocity was measured by timing a neutrally buoyant object over a measured section of stream. Three velocity measurements were taken for each tributary (Lind, 1979). From this information, stream discharge (flow) was calculated. Stream discharge is a critical parameter in comparing relative nutrient contributions (i.e., nutrient loading) among lake tributaries.

3.1.3 Phytoplankton Sample Collection

The methods used for phytoplankton sample collection and identification were those specified in the revised LEP guidelines. Two vertical plankton tows were taken using a 63μ mesh plankton net with an opening of 12 cm. The first tow was from a depth of five (5) feet to the surface. The second tow was from a depth of 15 feet to 10 feet, and included the thermocline. The plankton samples were immediately preserved with Lugol's solution and stored in labeled, opaque bottles. Phytoplankton were identified to species and enumerated using the Sedgwick-Rafter plankton counting procedure as outlined in the revised LEP guidelines (IDNR, 1990).

3.1.4 Sediment Sample Collection

To estimate the potential contribution of nutrients from the sediments, a composite sediment sample was collected from the lake bottom at the same location as the in-situ data and water samples. The sediment sample was collected using a Petite Ponar dredge, placed in a laboratory prepared container, and shipped to the analytical laboratory. The sample was analyzed for total nutrients (TP and TKN) and particle size (percentage of sand, silt, and clay).

3.1.5 Bathymetric Survey

Using electronic surveying equipment, a bathymetric survey of the entire lake was conducted. An Electronic Distance Measuring device (EDM), in conjunction with a boat-mounted recording fathometer, was used to obtain bottom depths along 21 transects on the lake surface. The EDM and boat mounted reflector provided known coordinates for positions at the endpoints and at approximately 100 foot intervals on each transect. This greatly increased the accuracy of the survey by ensuring accurate placement of each transect on the lake. The USGS benchmark at the lake outlet was used as the horizontal control for the bathymetric survey. The continuously recorded depth information was digitized into an IBM-PC compatible data file, which was then plotted using SURFER, a contour mapping program.

A secondary objective of the bathymetric survey was to estimate changes in lake volume due to potential increases in sedimentation. This was accomplished by comparing a 1955 hydrographic survey of the lake to the 1990 IS&T survey. Relative volumes of each contour interval, or strata, were compared using digital plannimetry. The volume of water contained in each strata was determined using the following equation (Wetzel and Likens, 1979):

$$V=\frac{h}{3}(A_1+A_2+\sqrt{A_1 A_2})$$

where:

V = volume

h = depth of stratum (contour interval; five feet for this analysis)

A_1 = area of upper surface

A_2 = area of lower surface

A depth volume graph was used to determine mean depth of the lake (i.e., the depth corresponding to 50% of the total lake volume).

3.2 WATERSHED SURVEY

Characterization of the current conditions in the Lake of the Woods watershed was oriented toward identifying the principal sources of sediment and nutrient loading within the Lake of the Woods watershed. Components of this survey included:

- Climatic data
- Hydrologic characterization
- Soil type delineation
- Land use delineation
- Sediment/nutrient modeling
- Septic system inputs
- Wetland identification.

3.2.1 Climate

Climate drives the hydrologic cycle, governing the hydrologic inputs (i.e., rainfall) and outputs (i.e., evaporation) of inland water bodies. Two types of atmospheric information were obtained and analyzed during the study: (1) general climatic data (e.g., temperature, rainfall, prevailing winds); and (2) precipitation chemistry data. General climatic conditions in the Lake of the Woods watershed were described from data compiled by the Soil Conservation Service (USDA, 1980). Estimates of total phosphorus and total nitrogen inputs from precipitation were interpolated from data collected at the closest Great Lakes monitoring stations (Benton Harbor, Michigan and Put-in-Bay, Ohio). No data were available to estimate dry loading for these parameters.

3.2.2 Hydrologic Data

The general topographic attributes of the drainage basin influence the behavior of water once it reaches the ground. In conjunction with climate, hydrologic features affect runoff volume, velocity (i.e., erosional capacity), and timing (i.e., flood potential). Characterization of hydrologic features for this study focused on two types of analyses: (1) a general description of watershed morphological attributes, and (2) calculation of an approximate mass-balance water budget. The watershed boundary was outlined on 7.5 Minute Series USGS topographic maps. Watershed features, including total area, slope, basin orientation, and drainage pattern were determined.

An annual water budget was developed for Lake of the Woods based on estimates of water mass inputs and outputs. Parameters considered as inputs included direct rainfall, runoff, and groundwater inputs. Parameters considered as outputs included lake outlet overflow, evaporation, and basin leakage. Annual rainfall volumes applied to the water budget were derived from data collected between 1951 and 1974 in Plymouth, IN (USDA, 1980). The average annual runoff value utilized was that reported for the Yellow River at Plymouth, IN (USGS, pers. comm., 1991). Lake evaporation was interpolated from figures supplied in the Water Atlas of the United States (Geraghty, et. al., 1973). Because data for springs and leakage in the lake were unavailable, these factors were assumed to be negligible. Lake overflow was calculated as the residual of inflow minus evaporation. No other water inflows or outflows were identified.

In addition to water budget parameters, estimates were made for hydraulic retention time. Hydraulic retention time is a measure of the time required for the volume of lake inflow water to equal the volume of the lake itself. It can be thought of as the period of time necessary to completely replace the volume of a lake. This parameter is very important in developing a restoration strategy for Lake of the Woods. The hydraulic retention time was computed as the ratio of lake water volume to the net annual inflow water volume. The formula used in calculating retention time (τ) is as follows:

$$\tau = \frac{V}{R+(P-E)}$$

Where:

τ = Hydraulic retention time (years)
V = Lake volume (cubic feet)
R = Average annual runoff (cubic feet/year)
P = Precipitation (cubic feet/year)
E = Evaporative losses (cubic feet/year)

In addition to runoff from the watershed, the lake receives direct input from precipitation, and loses water volume through evaporation from the lake surface. Average annual runoff (R) was determined by multiplying the watershed area by the average annual runoff value reported for the Yellow River in Plymouth, IN (USGS, pers. comm., 1991). Thus, direct precipitative input to the lake was computed by multiplying the surface area of the lake (416 acres) by the average annual rainfall. Evaporative loss (E) from the lake surface was determined in a similar manner. The result was expressed in years.

3.2.3 Soils

Soils within the Lake of the Woods watershed were identified and digitized using the Soil Survey of Marshall County (USDA, 1980). The soils data were summarized using a computer gridding program developed by IS&T. The information gathered was a critical component of the sediment/nutrient modeling (Section 3.2.5).

3.2.4 Land Use Delineation

Major land use patterns in the Lake of the Woods watershed were identified using recent (1986) aerial photographs (1:4800 scale) of the lake and watershed, USGS topographic maps (1:24,000 scale), and site reconnaissance. Several steps were necessary to develop the final land use map of the watershed.

First, the watershed boundary was outlined on topographic maps and digitized into IBM-PC compatible data files along with key geographical features (e.g., lake shorelines, streams, roads and towns). Land use within the watershed was delineated using aerial photographs and visual reconnaissance, and assigned to one of sixteen (16) unique land use categories. The land use types used are shown in Table 10. The border of each land use type was digitized into IBM-PC compatible data files. These files were overlain onto the watershed boundary and geographical feature data files. Coverage maps and tabular summaries of land use in the watershed, as well as the data files to produce them, were developed using IS&T proprietary software. The results of this task were used as input parameters for modeling sediment and nutrient loading to the watershed (Section 3.2.5).

Table 10. Land use categories designated in the watershed survey.

1. Water Surface
2. Wetlands (including approximate stream corridors)
3. Forest (tree groups larger than 0.25 acre)
4. Open/Fallow Land
5. Pasture and Grazed Land
6. Row Crops (corn, beans, etc.)
7. Non-row Crops (wheat, hay, etc.)
8. Orchards and Vineyards
9. Feedlot
10. Low Density Residential
11. High Density Residential
12. Institutional
13. Commercial/Industrial
14. Recreational
15. Resource Extraction (gravel pits)
16. Landfill

3.2.5 Sediment/Nutrient Modeling

Information on climate, hydrology, land use, and soils were combined to provide input parameters for use in the Agricultural Non-Point Source Pollution Model (AGNPS), a system developed by the U.S. Department of Agriculture-Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service. The PC-based model was designed to simulate the sediment and nutrient contributions from watersheds under predefined hydrologic conditions. AGNPS operates on a grid basis and requires that the watershed be divided into a series of discrete squares, or cells. Twenty-two input parameters, covering a wide range of physical and chemical characteristics are assigned to each cell (Table 11). Sediment and nutrients are routed through the watershed; their concentrations in each cell being a function of upstream loading and the unique cell attributes, which can either increase or diminish the non-point pollution load. Sediment, nutrient, and hydrologic characteristics may be summarized for any cell along the flow path and at the watershed outlet. The model also allows the user to highlight cells with specific characteristics, such as high sediment phosphorus. In addition, land use and other characteristics may be hypothetically altered to determine the effect of future changes on sediment and nutrient loading. The model provides estimates for single precipitation events only, so the user must define a "design storm" for the analysis.

The developers of the AGNPS model recommend a cell size of 40 acres for watersheds greater than 2000 acres, however IS&T used a 25-acre cell size for the Lake of the Woods watershed. This cell size was chosen as the one to most accurately reflect the watershed characteristics. Although smaller cell sizes mean greater numbers of cells, the increase in precision of the model results outweighed the additional labor required for data entry.

Table 11. Input parameters used in the AGNPS model [1].

TITLE	DESCRIPTION
Cell Number	ID number of current cell
Receiving Cell	ID of cell receiving outflow from current cell
SCS Curve Number	Relates runoff mass to rainfall mass (inches)
Field Slope	Mean slope of fields (%)
Slope Shape	Indicates concave, convex or uniform slope shape
Slope Length	Indicates average field slope length (feet)
Channel Slope	Mean slope of stream channel (%)
Side Slope	Mean slope of stream channel banks (%)
Roughness	Manning's Roughness Coefficient for channels
Soil Erodibility	K-Factor from Universal Soil Loss Equation
Crop Practice	C-Factor from Universal Soil Loss Equation
Conservation Practice	P-Factor from Universal Soil Loss Equation
Surface Condition	Indicates degree of land surface disruption
Aspect	Principal drainage direction
Soil Texture	Indicates sand, silt, clay or peat
Fertilization	Indicates level of added fertilizer
Incorporation	Indicates % of fertilizer left on soil after storm
Point Source Flag	Indicates presence/magnitude of any point source
Gully Source	Override estimate of gully erosion magnitude
COD	Level of chemical oxygen demand generated
Impoundment Flag	Indicates presence/absence of terrace systems
Channel Flag	Indicates presence/absence of defined streams

[1] Parameters represent estimated conditions within each cell.

Each AGNPS cell was characterized according to the parameters listed in Table 11. The design storm chosen was a two year, 24-hour event. This is defined as the largest storm that can be expected to occur once every two years, based on a 30 year period of record. For Lake of the Woods, this was a 2.7 inch rainfall (U.S. Department of Commerce, 1966). Nutrient, sediment and runoff maps were produced using the AGNPS Graphical Interface System.

3.2.6 Septic System Survey

Most lake-side septic systems are subject to limited capacity and frequent high water tables, therefore elevated concentrations of phosphorus may be transported to the waterway via groundwater. The study completed in 1982 on Lake of the Woods found that the contribution of phosphorus to the lake, by septic systems, was 22% of the external phosphorus load and 12.76% of the total phosphorus load (Senft and Roberts, 1982). Factors that generally influence nutrient export from septic systems to a nearby surface water body include: (1) capacity of the leach field soils to attenuate nutrients; (2) distance between the leach fields and the lake; (3) the number of people using septic systems; and (4) per-capita inputs to septic systems.

In an effort to confirm the contribution of septic systems to phosphorus loading in Lake of the Woods, the following information was assembled:

- Number of lakeshore residences
- Average age of these residences
- Average number of individuals per dwelling
- Residence type (i.e., permanent or seasonal)
- Soil characteristics

A predictive framework was constructed, based on the available data, to provide an assessment of the overall septic load to Lake of the Woods.

3.2.7 Annualized Phosphorus Loading

The input-output model, LAKEPHOS, was used to provide an annualized estimate of phosphorus loading to Lake of the Woods based on land-use categories identified in the watershed. Information on the relative contribution of septic systems to total phosphorus loading, as well as predicted in-lake average phosphorus concentrations were also determined using this model.

3.2.8 Wetland Identification

Existing wetland areas within the Lake of the Woods watershed were identified using aerial photos of the watershed and digitized as a separate land use category as described in Section 3.2.4. In addition, a summary map of wetland areas in Marshall County was obtained from the IDNR, Division of Fish and Wildlife. This map, prepared using the IDNR's geographic information system, was compiled from the U.S. Fish and Wildlife Service's National Wetland Inventory Maps. Areas of hydric soils (i.e., soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part) were also identified based on the Marshall County Soil Survey. Identification of hydric soils is an important first step in the process of restoring wetland areas that have been drained for agricultural purposes.

SECTION 4. RESULTS AND DISCUSSION

4.1 LAKE SURVEY

This investigation included in-situ, chemical and biological water quality measurements; sediment analyses; and bathymetric mapping. These data were used to summarize conditions in the lake and assess its current trophic status.

4.1.1 In-situ Measurements

In-situ water quality measurements are presented in Figures 4a-4d and Table 12. These data indicate that

Table 12. Lake of the Woods in-situ water quality measurements. (6 September 1990)

DEPTH (ft.)	TEMP (C)	DO (mg/L)	pH	COND (μmhos/cm)	% TRANS.	SECCHI DISK (ft)
0.0	27.2	11.29	8.8	441	3.1	1.64
3.0	27.2	11.27	8.8	441	3.0	
4.0	27.2	11.23	8.8	442		
5.0	27.0	11.04	8.8	442	2.9	
6.0	26.8	10.70	8.8	444		
7.0	26.4	8.20	8.8	446	11.9	
8.0	25.1	7.34	8.6	456		
9.0	25.1	6.85	8.6	459	14.0	
10.0	24.8	6.16	8.5	460		
12.0	24.7	5.50	8.4	462		
14.0	24.5	4.23	8.3	466		
15.0	24.1	2.63	8.0	470		
16.0	23.6	0.66	8.0	472		
18.0	21.3	0.15	7.8	497		
20.0	20.7	0.08	7.7	509		
25.0	19.3	0.05	7.6	536		
30.0	17.2	0.06	7.4	571		
35.0	16.3	0.06	7.3	584		
40.0	15.4	0.03	7.2	623		
43.0	14.8	0.03	7.1	658		
43.5 (bottom)						

Lake of the Woods was thermally stratified at the time of sampling, with the thermocline occurring between 15 and 18 feet (Figure 4a).

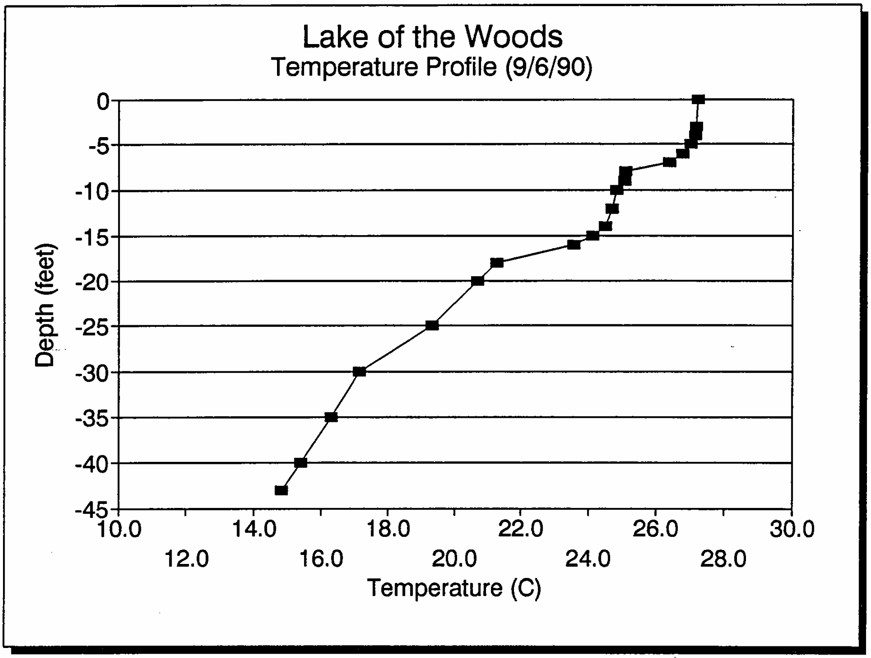

Figure 4a. In-situ temperature profile for Lake of the Woods (6 September 1990).

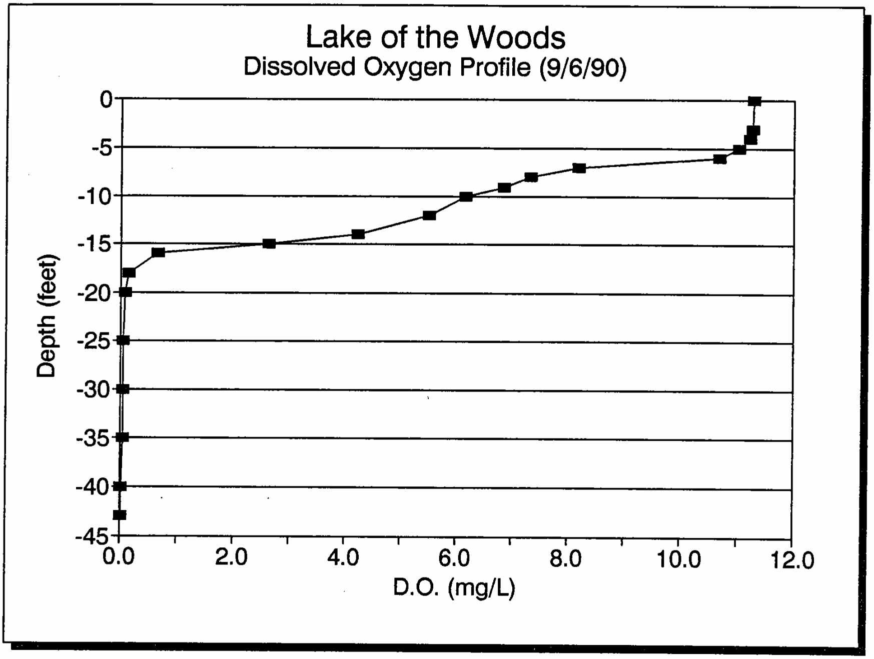

Figure 4b. In-situ DO profile for Lake of the Woods (6 September 1990).

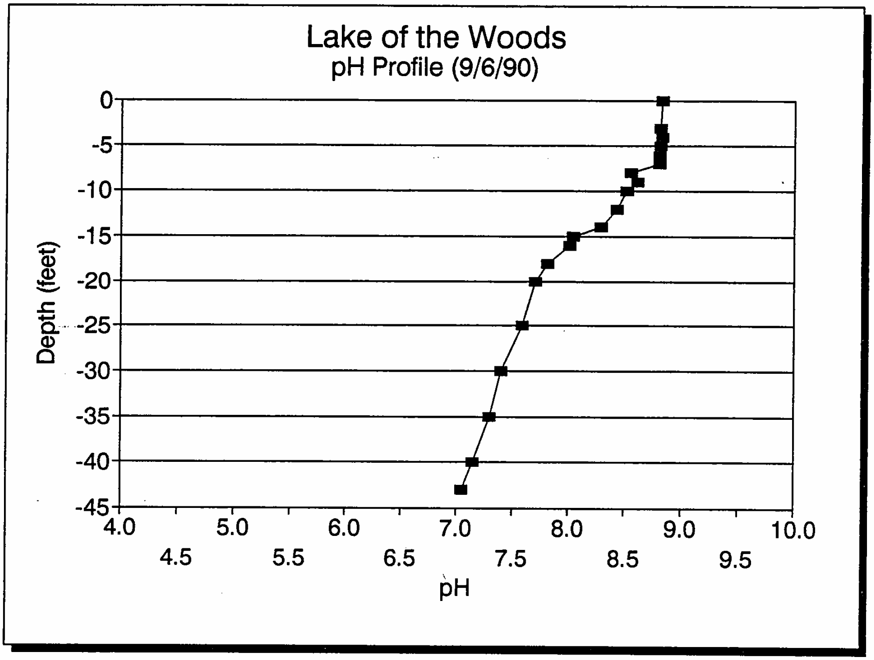

Figure 4c. In-situ pH profile for Lake of the Woods (6 September 1990).

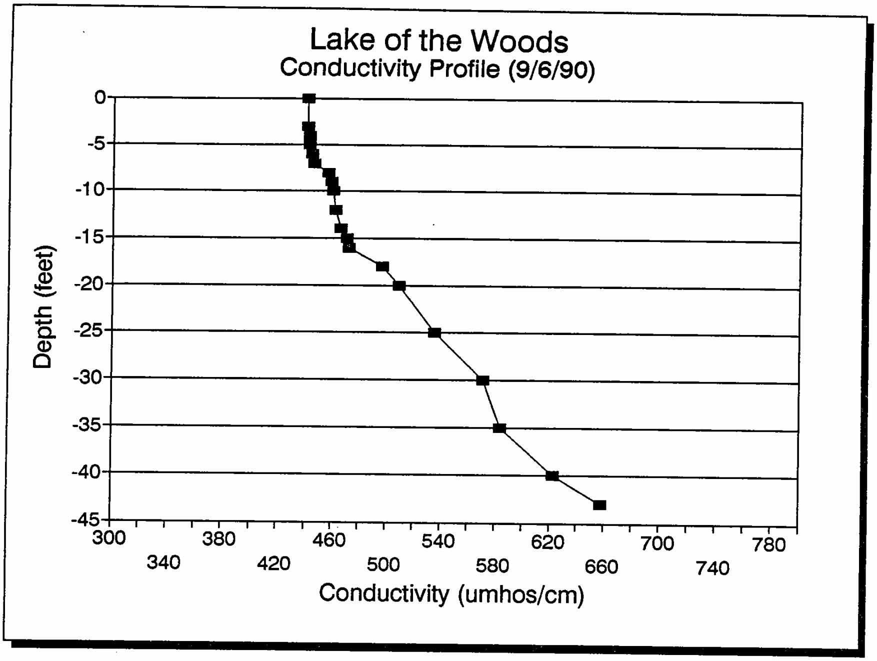

Figure 4d. In-situ conductivity for Lake of the Woods (6 September 1990).

Dissolved oxygen (DO) concentrations were between 11.29 and 8.20 mg/L from the surface to a depth of seven (7) feet. All readings from the surface through seven (7) feet were supersaturated. DO concentrations steadily decreased from 7 to 15 feet, with anoxic conditions from this depth to the lake bottom. The clinograde DO profile (Figure 4b) is generally indicative of productive, eutrophic lakes, and is usually observed during periods of thermal stratification when oxygen consumption exceeds oxygen production in the bottom waters (i.e., hypolimnion). Because water circulation is reduced during this period, less oxygen can be distributed to the hypolimnion from the surface.

The pH distribution in the water column was representative of a productive stratified lake, with values above the thermocline higher than those below (Figure 4c). The pH values above the thermocline were constant at 8.8. Below the thermocline, values ranged from 8.6 to 7.0. The majority of freshwater lakes have a pH range from 6 to 9, and are regulated by a natural carbonate buffering system. The distribution of pH in the water column is influenced by the photosynthetic utilization of carbon dioxide (CO_2) in the trophogenic zone (i.e., area inhabited by light dependent organisms) and respiratory generation of CO_2 throughout the water column and sediments. If the accumulation of CO_2 exceeds oxygen consumption, and the hypolimnion becomes anaerobic, the pH will decrease markedly. Where photosynthetic activity is particularly intense, the pH will increase in response to the decrease in CO_2 due to phytoplankton uptake.

The conductivity measurements increased with depth (Figure 4d). This is a commonly observed pattern, particularly in stratified lakes with anoxic hypolimnion. Conductivity, in common bicarbonate-type lake water, is roughly proportional to the concentration of the major ionic constituents (Wetzel, 1983).

4.1.2 Chemical Measurements

Water quality analyses were conducted on both in-lake samples and tributary samples, and are presented in Tables 13 and 14, respectively. Results for both types of samples collected are discussed below.

In-Lake Samples

Results of the in-lake sample analyses showed a higher concentration of ammonia (N-NH_4), total Kjeldahl nitrogen (TKN), ortho-phosphorus (OP), and TP in the bottom sample. The high concentration of NH_4-N was attributed to anaerobic conditions at that depth since N-NH_4 concentrations are typically elevated in poorly oxygenated waters. Relatively high concentrations of TKN were also observed near the sediment water interface. TKN represents organically bound nitrogen, and elevated concentrations are representative of the higher levels of organic matter present in the hypolimnion. The increase in total and soluble phosphorus (i.e., TP and OP) content near the lake bottom is common in eutrophic lakes with strongly clinograde oxygen profiles, and would indicate nutrient release from the sediments (Wetzel, 1983). Additionally, the NO_3-N concentrations decreased in the hypolimnion as a result of denitrification processes that occur in anaerobic environments.

Table 13. Water quality results for in-lake samples collected at Lake of the Woods.

SAMPLE ID	SAMPLE DEPTH (ft)	DATE COLLECTED	TIME COLLECTED	CHL a (mg/m^3)	TON (mg/L)	$N-NH_4$ (mg/L)	NO_3 (mg/L)	TKN (mg/L)	OP (mg/L)	TP (mg/L)	TSS (mg/L)
LOW-SURF	3.0	09/06/90	10:55	50.7	1.9	<0.50	0.92	1.9	<0.01	<0.10	17.0
LOW-BOTM	40.0	09/06/90	11:05	3.0	1.2	7.60	<0.01	8.8	0.23	0.42	< 2.0

CHL a = Chlorophyll a; TON = Total Organic Nitrogen; $N-NH_4$ = Ammonia; NO_3 = Nitrate;
TKN = Total Kjeldahl Nitrogen; OP = Ortho Phosphorus; TP = Total Phosphorus; TSS = Total Suspended Solids
< = Value Lower than Detection Limit

SAMPLE ID	SAMPLE DEPTH (ft)	DATE COLLECTED	TIME COLLECTED	FECAL COLIFORM (#/100 ml)	FECAL STREP (#/100 ml)	E. coli (#/100 ml)	TOTAL COLIFORM (#/100ml)
LOW-SURF	3.0	09/06/90	10:55	3	5	3	30
LOW-BOTM	40.0	09/06/90	11:05	3	2	1	20

Table 14. Water quality results for Lake of the Woods tributaries.

SAMPLE ID	DATE COLLECTED	TIME COLLECTED	NO_3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	FECAL COLIFORM (#/100ml)	E. coli (#/100ml)	FLOW RATE (cfs)
Walt Kimble Ditch	04/03/91	11:15	5.2	1.78	0.045	<4.0	42	7	41.6
Martin Ditch	04/03/91	10:40	5.7	0.95	0.047	<4.0	27	Absent	38.0
Lake Outlet	04/03/91	09:30	3.6	1.60	0.065	<4.0	10	Absent	209.3

TP = Total Phosphorus; NO_3 = Nitrate; TKN = Total Kjeldahl Nitrogen; TSS = Total Suspended Solids

The ratio of total nitrogen to total phosphorus, commonly referred to as N:P, is often used to evaluate the relative importance of these two algal nutrients, which are quickly taken up in their soluble forms (i.e., ortho-phosphorus and nitrate). Although the concentrations of the soluble forms are not necessarily indicative of available supply, the ratio of the total nutrient concentrations can be used to assess which nutrient will be limiting (i.e., the first to be used completely following continued growth) to plant growth (Welch, 1980). Nitrogen is rarely limiting in freshwater systems due to its abundance in the atmosphere and availability through nitrogen fixation by blue-green algae. Phosphorus however, is rapidly incorporated in phytoplanktonic algae, often in excess of immediate physiological requirements. Development of specific long-term management strategies is often dependent upon which of these two nutrients is limiting to the aquatic resource.

N:P ratios greater than 21:1 strongly suggest that phosphorus is the limiting nutrient, while ratios less than 13:1 are usually indicative of nitrogen limitation. Either nitrogen or phosphorus may be limiting in lakes with intermediate ratios, but by controlling phosphorus, it can be made the limiting factor (Cooke, et. al., 1986). The N:P ratios of the surface (28.2) and bottom (21.0) samples indicate phosphorus limitation in Lake of the Woods at the time of sampling.

Tributary Samples

Nutrient concentrations in the two Lake of the Woods tributaries that were sampled on 4/3/91 can be categorized as moderately high. Total phosphorus in both Martin and Walt Kimble Ditches was just under the 0.05 mg/L level that the U.S. EPA considers indicative of eutrophic conditions. This criteria is designed for lakes, however it is useful in predicting the potential impact of tributary nutrients on lake water quality. The outlet TP concentration slightly exceeded the 0.05 mg/L criteria. No drinking water standards exist for total phosphorus. Nitrate is of concern in surface waters at concentrations greater than 10 mg/L due to the potential for deleterious health effects for infants. The drinking water standard for nitrate is 10 mg/L for infants, and 20 mg/L for children and adults. Nitrate in the two tributaries and the lake outlet ranged from 3.6 to 5.7 mg/L. The maximum nitrate value was measured in samples collected from Martin Ditch (5.7 mg/L). TKN, a measure of organically bound nitrogen, was relatively low in all three samples. TSS concentrations were very low, indicating that water quality at the time of sampling was not influenced by sediment transported in storm runoff.

4.1.3 Biological Measurements

The results of the Lake of the Woods chlorophyll a analyses (Chla) indicate that the greatest amount of photosynthetic activity was occurring near the surface. The pigment concentration observed at a depth of three feet (50.7 mg/m^3) indicates very productive waters, and is within the range of concentrations found in eutrophic lakes (Wetzel, 1983). As expected, the Chla concentration in the bottom sample dropped as light and temperature became limiting to phytoplankton.

The results of phytoplankton identification and enumeration for Lake of the Woods showed a diverse algal community. Twenty-one (21) species representing four (4) classes were identified (Table 15). The algal community was dominated by blue-greens, which comprised 67.4% of the 5 foot to surface tow, and 66.6% of the 15 foot to 10 foot tow (Figures 5a and 5b). Numerically, the dominant algal specie was the blue-green algae Microcystis aeruginosa. Other numerically important species included the blue-green algae Aphanizomenon flos-aquae, and the diatom Synedra radians. Blue-green algal dominance is often associated with eutrophic conditions.

Bacteria counts in the Lake of the Woods samples were all well below the current standard established by the IDEM for whole body contact recreation in lakes and reservoirs. Both samples had counts well below the current IDEM standard for E. coli (<235 organisms per 100 ml sample), as well as counts below the previous fecal coliform IDEM standard for full body contact recreation (i.e., <400 organisms per 100 ml). There is no total coliform standard for full body contact recreation. In waters to be treated for drinking water purposes, however, total coliform counts must be below 5,000 organisms per 100 ml of sample. The total coliform cell concentrations found in Lake of the Woods meet this guideline.

Fecal coliform and E. coli results for the tributary and lakeshore ditch samples were all within the IDEM standards described above. While generally not disease producing themselves, the presence of fecal coliform is indicative of the presence of pathogens in drinking water, and is therefore classified as an "indicator organism". The presence of E. coli bacteria confirms that human waste is present in the water supply, and is therefore a stronger test in terms of human health effects.

4.1.4 Trophic State Assessment

The biological, chemical and physical characteristics of a lake can be incorporated into an index number to describe its trophic state. Historically, trophic classifications have been based on the division of the trophic continuum into a series of classes. Traditional systems divide the continuum into three classes (i.e., oligotrophic, mesotrophic and eutrophic), but frequently offer no clear delineation of these divisions. Calculating a trophic state index allows a quantitative description of the degree of eutrophication in a lake, and provides a basis for numerically comparing the lake's trophic status over a period of time and against that of other lakes.

There are several numerical trophic classification systems currently used within the scientific community. A previous trophic state assessment of Lake of the Woods was conducted using the BonHomme Eutrophication Index and is documented in the Indiana Lake Classification System and Management Plan (IDEM, 1986). The index was developed by Harold BonHomme of IDEM. Index points are assigned based on diverse chemical, physical and biological measurements in the lake. A lake may receive a Eutrophication Index (EI) number ranging from 0 to 75, with values near 0 being the least eutrophic.

Another numerical index that is widely reported in the literature for trophic state assessment is the Carlson Trophic State Index (TSI). Carlson (1977) based his index on algal biomass using the log transformation of Secchi disk transparency, a physical measurement, as an estimate of biomass. Since Chla and TP

Table 15. Lake of the Woods phytoplankton identification and enumeration (6 September 1990).

	TOTAL PLANKTON PER LITER SAMPLED	
	5 FT. TO SURF.	15 FT. TO 10 FT.
SPECIES		
Chlorophyta (green algae)		
Chlamydomonas sp.	1,073	
Scenedesmus abundans	1,073	
Scenedesmus quadricauda		2,244
Pediastrum duplex		780
Total Chlorophyta per liter	2,146	3,024
Chrysophyta (diatoms, chrysophytes, etc.)		
Synedra radians	22,344	16,587
Cyclotella stelligera	2,147	1,464
Melosira italica	1,073	
Fragilaria crotonensis		1,464
Synedra ulna		781
Nitzschia palea		781
Navicula cryptocephala veneta		780
Fragilaria vaucheria		780
Total Chrysophyta per liter	25,564	22,637
Pyrrophyta (yellow-browns)		
Ceratium hirudinella	1,073	
Rhodomonas minuta	1,073	780
Cryptomonas erosa		1,464
unident. dinoflagellate		780
Total Pyrrophyta per liter	2,146	3,024
Cyanophyta (blue-greens)		
Microcystis aeruginosa	38,345	36,101
Aphanizomenon flos-aquae	16,002	17,368
Anabaena planctonica	3,220	2,244
Oscillatoria sp.	3,220	1,464
Anabaena flos-aquae	1,073	
Total Cyanophyta per liter	61,860	57,177
Total plankton per liter	91,716	85,862

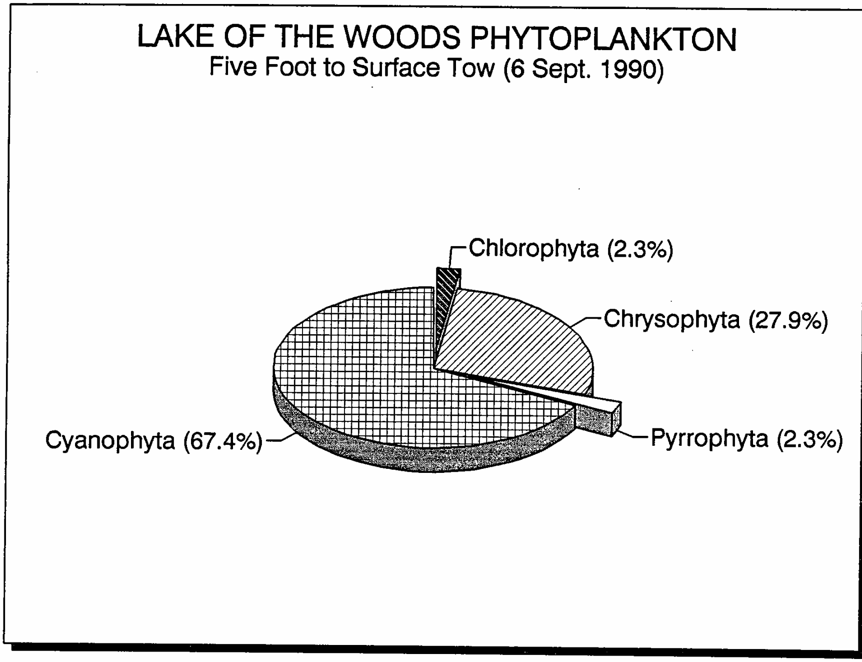

Figure 5a. Percentages of phytoplankton classes represented in the 5 foot to surface tow.

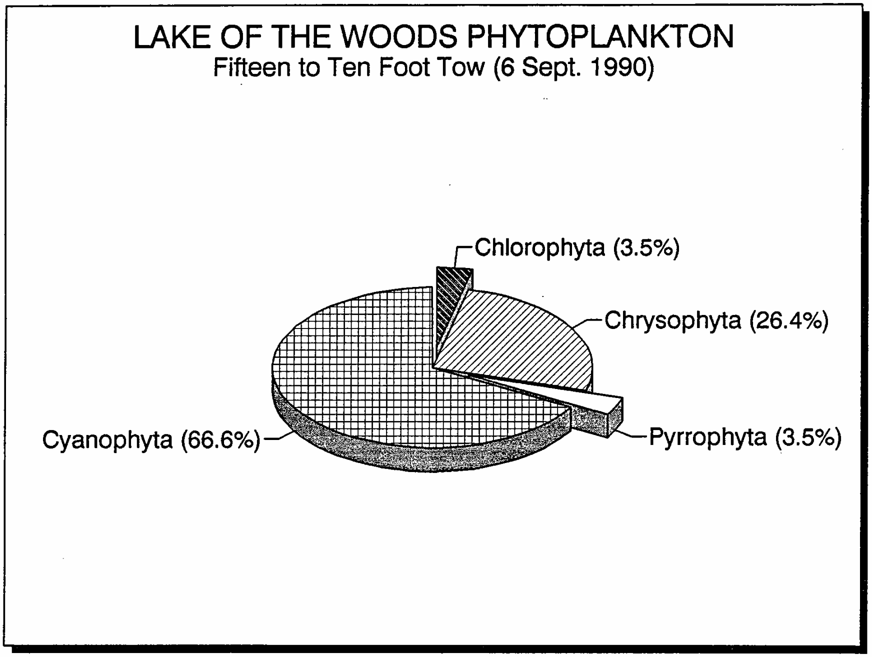

Figure 5b. Percentages of phytoplankton classes represented in the 15 foot to 10 foot tow.

concentrations are often correlated with transparency, a TSI number may also be calculated from these biological and chemical measurements. All three measurements are taken from surface waters where phytoplankton productivity is at its peak. The equations used for computing the Carlson TSI are:

$$TSI(SD) = 60 - (14.41 \ln SD) \tag{1}$$

Where:
TSI(SD) = TSI based on Secchi disk transparency
SD = Secchi transparency (meters)

$$TSI(Chla) = (9.81 \ln Chla) + 30.6 \tag{2}$$

Where:
TSI(Chla) = TSI based on chlorophyll concentration
Chla = Chlorophyll a (mg/m^3)

$$TSI(TP) = (14.42 \ln TP) + 4.15 \tag{3}$$

Where:
TSI(TP) = TSI based on total phosphorus concentration
TP = Total phosphorus (mg/m^3)

The Carlson TSI classifies lakes on a scale of 0 to 100, with each major scale division (i.e., 10, 20, 30, ...) representing a doubling in algal biomass. Under ideal circumstances, the three separate TSI values should be similar, however the index values will exhibit some variability. This variability reveals basic differences in the ecological functioning of the aquatic system. The accuracy of Carlson's TSI based on Secchi disk measurement alone is diminished by the presence of non-algal particulate matter or highly colored water. The index number derived from the Chla values, when available, is best for estimating algal biomass, and priority should be given for its use as a trophic state indicator (Carlson, 1977).

A BonHomme Eutrophication Index (EI) number was calculated for Lake of the Woods using the water quality and biological data collected during the 6 September 1990 field survey. A breakdown of the points assigned for each of the EI criteria is shown in Table 16. The number of points assigned was based on a revised scale developed by the IDEM staff. This revision allows comparison of current EI values with those based on data collected by the ISBH in the 1970's.

Previously, the IDEM calculated an EI number of 42 for Lake of the Woods (IDEM, 1986). More recent data, collected in July 1987 by IDEM, resulted in an EI number of 48 (BonHomme, pers. comm., 1990). The EI number based on data collected 6 September 1990 was calculated to be 50, placing the lake within the Class Two trophic category, as previously described in Section 1.2. An EI value of 50 marks the upper boundary of Class Two and indicates that Lake of the Woods may be moving into an advanced state

Table 16. **BonHomme Eutrophication Index calculations for Lake of the Woods.**

Parameter and Range	Range Value	Range Observed	Point Value
Total Phosphorus (mg/L)			
Observed Mean: 0.21 mg/L			
At least 0.03	1		0
0.04 to 0.05	2		0
0.06 to 0.19	3		0
0.20 to 0.99	4	X	4
Greater than 0.99	5		0
Soluble Phosphorus (mg/L)			
Observed Mean: 0.12 mg/L			
At least 0.03	1		0
0.04 to 0.05	2		0
0.06 to 0.19	3	X	3
0.20 to 0.99	4		0
1.00 or more	5		0
Organic Nitrogen (mg/L)			
Observed Mean: 1.55 mg/L			
At least 0.05	1		0
0.60 to 0.80	2		0
0.90 to 1.90	3	X	3
2.0 or more	4		0
Nitrate (mg/L)			
Observed Mean: 0.46 mg/L			
At least 0.30	1		0
0.40 to 0.80	2	X	2
0.90 to 1.90	3		0
2.0 or more	4		0
Ammonia (mg/L)			
Observed Mean: 3.8 mg/L			
At least 0.30	1		0
0.40 to 0.50	2		0
0.60 to 0.90	3		0
1.0 or more	4	X	4
Percent oxygen saturation at 5 feet			
Observed Value: 143%			
114% or less	0		0
115% to 119%	1		0
120% to 129%	2		0
130% to 149%	3	X	3
150% or more	4		0

Table 16. **BonHomme Eutrophication Index calculations for Lake of the Woods (concluded).**

Parameter and Range	Range Value	Range Observed	Point Value
Percent of Water Column with at least 0.10 mg/L of DO			
Observed Value: 46%			
28% or less	4		0
29% to 49%	3	X	3
50% to 65%	2		0
66% to 75%	1		0
76% to 100%	0		0
Secchi Disk Transparency			
Observed Value: 1.6 feet			
5 feet or less	6	X	6
Greater than 5 feet	0		0
Light Transmission at 3 feet			
Observed Value: 3%			
0% to 30%	4	X	4
31% to 50%	3		0
51% to 70%	2		0
71% or greater	0		0
Total Plankton from 5 foot Tow (#/L)			
Number of Organisms per Liter: 91,716			
Less than 4,700/L	0		0
4,701/L to 9,500/L	1		0
9,501/L to 19,000/L	2		0
19,001/L to 28,000/L	3		0
28,001/L to 57,000/L	4		0
57,001/L to 95,000/L	5	X	5
95,001/L or more	10		0
Blue-green dominance	5	X	5
Total Plankton from Thermocline Tow (#/L)			
Number of Organisms per Liter: 85,862			
Less than 9,500/L	0		0
9,501/L to 19,000/L	1		0
19,001/L to 47,000/L	2		0
47,001/L to 95,000/L	3	X	3
95,001/L to 190,000/L	4		0
190,001/L to 285,000/L	5		0
285,001/L or more	10		0
Blue-green dominance	5	X	5
Population of 950,000 or more	5		0
			==
INDEX VALUE			50

of eutrophication. A comparison of the data used to construct the index showed significant increases in TP and $N\text{-}NH_4$ concentrations. A significant decrease in concentration was noted for NO_3, as well as a decrease in the percentage of water column with at least 0.1 mg/L of dissolved oxygen.

Calculation of the Carlson TSI was based on the Chla and TP concentrations in the surface waters, as well as the Secchi disk transparency for Lake of the Woods. Table 17 presents the results of these calculations. The range of TSI values was between 69 and 70. Because the surface TP concentration was below detection limits (i.e., < 0.10 mg/L), the TSI based on that value was calculated using the detection limit of 0.10 mg/L. Therefore, the TSI(TP) of 71 represents the maximum value for Lake of the Woods on the date of sampling. Lakes with TSI values in the range of 60 to 70 are considered eutrophic, and are characterized by blue-green algal dominance, with algal scums and extensive macrophyte growth probable (Carlson 1979).

Table 17. Carlson Trophic State Index calculations for Lake of the Woods.

SAMPLE DATE	SECCHI DISK (m)	TSI (SD)	CHLOROPHYLL (mg/m3)	TSI (Chla)	TP (mg/m3)	TSI (TP)
09/06/90	0.5	70	50.7	69	<100	<71

A comparison of the calculated TSI values shows that Secchi disk and Chla based values are equivalent, and most likely greater than the TP based value. This would indicate that light attenuation was dominated by algae, and the lake was phosphorus limited on the date of sampling (Carlson, 1983).

Both the BonHomme EI and the Carlson TSI classify Lake of the Woods as eutrophic at the time of sampling. It should be noted that the data used to construct these indices are derived from a single sampling event and are only representative of lake conditions on a single day in mid-summer. Better representation of trophic state could be attained through increased lake monitoring throughout the summer growing season. Such high resolution sampling was beyond the scope of this investigation.

4.1.5 Sediment Sample Results

The results of the analyses on the sediment sample collected from Lake of the Woods are shown in Table 18. The samples were collected 6 September, 1990. For comparison purposes, this table also shows mean background concentrations of TP and TKN in sediments at 83 sites throughout Indiana, surveyed by IDEM from 1985 to 1987 (Indiana 305B Report, 1986-1987). These mean values represent sediment concentrations at sites upstream of all known point sources of pollution, including industrial discharges and combined sewer overflows. As such, they are considered to represent unpolluted lake and stream sediments statewide. The IDEM provides these estimates because no criteria for sediment concentrations of priority pollutants have been established by the state or federal government. As guidelines for

Table 18. Lake of the Woods sediment sample analyses.

SAMPLE ID	DATE COLLECTED	% SOLIDS (g/100g)	TP (mg/Kg)	TKN (mg/Kg)	% SAND	% SILT	% CLAY
Composite	09/06/90	14	179	10,714	85	11	4
IDEM Background Level			610	1,500			

interpreting sediment data, IDEM has defined four levels of concern: low, medium, high, and unknown. Low concern is defined as 2-10 times background levels, medium concern as 10-100 times background, and high concern as any concentration greater than 100 times background. Using the IDEM guidelines, all results obtained fall into the low concern category. The maximum factor by which a parameter exceeded the background level was 7 for TKN. Although still in the IDEM "low concern" category, the TKN value for the Lake of the Woods sediments (10,714 mg/kg) is much higher than other Northern Indiana lakes sampled by IS&T over the last two years. High sediment nitrogen suggests over-application of nitrogen fertilizer to agricultural lands over a period of many years. Results for sediment TP were approximately 3.4 times less than the IDEM background level.

The results of the particle size analyses indicated that sand was the dominant particle size, comprising 85 percent of the total sediment composition. Resuspension following a disturbance to the lake bottom, such as dredging, would therefore be expected to have minimal and short term effects on water clarity.

4.1.6 Bathymetric Survey

A bathymetric map of Lake of the Woods is shown in Figure 6. The following section describes the results of an analysis of differences between the 1990 bathymetric survey and a similar survey conducted in 1955 by IDNR (a 35 year period of comparison). As a preface to the discussion, changes to the lake itself were the focus of this analysis. Changes in depth within the canals that were present in 1955 were not determined. However, these canals, as well as those recently constructed, are shown in the 1990 bathymetric map.

In general, the 1990 map closely resembles the bathymetric survey of 1955. The deepest areas of the lake corresponded to those shown on the 1955 map. Depths 40 feet or greater were found in three areas of the lake. The maximum depth found (just under 47 feet) was in the "hole" along the eastern shore in the southern half of the lake. Two deep areas are located immediately adjacent to each other in this area, the deeper one being to the north. A depth of 45 feet was shown in this location on the 1955 map. The area shown as the deepest location on the 1955 map is the northern deep basin of the lake, where a depth of 48 feet was found in 1955. The 1990 survey found a maximum depth of 43 feet at this location.

Differences in the volume of the lake were determined for each of nine contour intervals, ranging from the 0-5 foot level to the 40-45 foot level, using digital planimetry and the equation presented in Section

3.1.5. The volume of the lake determined from the 1990 survey was 6,163 acre-feet. Using the same methods, the volume of the lake based on the 1955 map was 6,373 acre-feet, three percent greater than the 1990 lake volume. Over the 35 year period of comparison, the 210 acre-foot loss in volume between the two maps results in an annual sedimentation rate of 0.17 inches per year. The U.S. EPA Lake and Reservoir Guidance Manual (EPA, 1990) states that sedimentation rates in freshwater lakes typically range from 0.10 to 0.50 inches per year. The rate determined for Lake of the Woods should therefore be considered moderate.

An estimate of the percent change in volume, from 1955 to 1990, for each of the nine contour intervals, is shown in Figure 7. A negligible increase in volume was seen in the surface to five foot level, with small decreases (less than 10%) from the 5-10 foot contour through the 30-35 foot contour. The volume of water contained in these intervals represents over 95% of the total volume of the lake. The three deepest intervals had the greatest loss of volume, on a percentage basis. The 40-45 foot interval decreased by 74% over the volume of the same interval in 1955. The loss of volume in the 35-40 foot interval was 38%, and in the 30-35 foot level 17%. Again, the percentage losses are significant, however the total decrease in lake volume within these three contour intervals represents a small fraction (approximately 3%) of the total 1990 lake volume.

It should be noted that for consistency, the total 1955 lake volume used for this comparison was a calculated value, based on the digital planimetric methods, in contrast to using the 6,810 acre-foot volume reported on the 1955 map itself. If the 6,810 figure is used, the sedimentation rate increases to 0.53 inches per year because of the much larger difference (loss) of lake volume. Given the many potential sources of error in this type of comparison, such as differences in accuracy of the depth measurements, differences in field methodology, and differences in the methods used to generate the contour lines in 1955 versus 1991, it was apparent that the best estimate of changes in lake volume would be based on the calculated 1955 lake volume. This at least ensured that, despite probable differences in field techniques and instrumentation, the lake volume estimates would be derived using the same methodology. The sedimentation rate determined using the calculated 1955 volume (0.17 inches per year) is therefore the most confident estimate. The same rate using the 6,810 acre-foot volume (0.53 inches per year) should be viewed as a maximum rate.

4.2 WATERSHED SURVEY RESULTS

The findings of the watershed survey are presented in this section. Topics addressed include climate, hydrology, soils, land use, and sediment/nutrient transport. It is critical to understand these characteristics because they influence the dynamics of water, sediment, and nutrients associated with the lake. The results of the AGNPS modeling exercise were an important tool for integrating the effects of these factors and interpreting their significance. Additionally, the septic system survey results and identification of wetlands are presented.

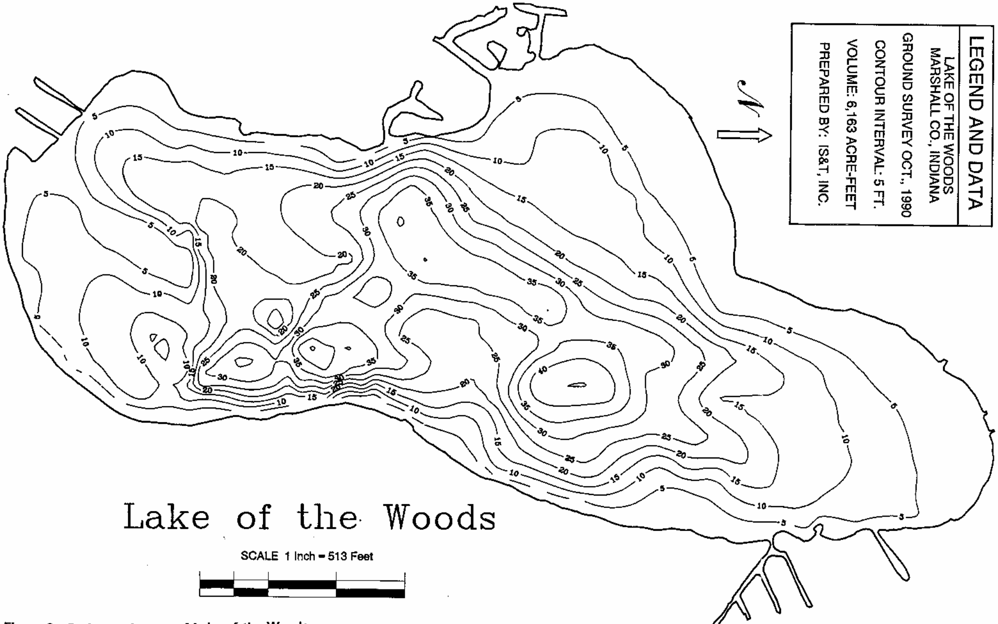

Figure 6. Bathymetric map of Lake of the Woods.

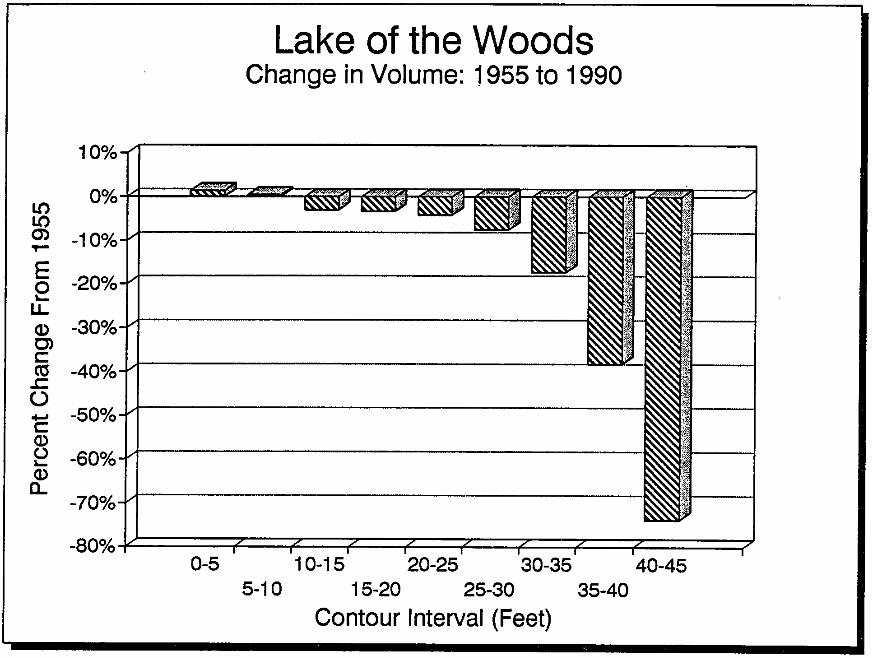

Figure 7. Percent change in lake volume: 1955 - 1990.

4.2.1 Climate

Climate is often considered a "master variable" in controlling the condition of inland water bodies. It drives the hydrologic cycle, directly governing hydrologic inputs (e.g., rainfall and runoff) and outputs (e.g., evaporation). Climate affects soil moisture conditions and plant growth, which in turn influence the potential for surface water losses through evapotranspiration and infiltration. In addition, the wetfall component of the atmospheric deposition of nutrients (i.e., phosphorus and nitrogen) is governed by climate. Factors to consider when analyzing climate include:

- Type of precipitation
- Timing of precipitation
- Duration of precipitation
- Direction of storm movement
- Temperature.

Selected monthly climatic data for the Lake of the Woods region are listed in Table 19. Discussion of

Table 19. Selected climatic data for the Lake of the Woods watershed. (USDA, 1980)

Month	Precip (In)	Max Temp (°F)	Min Temp (°F)
January	1.89	32.9	15.8
February	1.70	37.1	19.2
March	2.51	47.1	27.3
April	4.12	62.3	38.4
May	3.43	73.5	48.0
June	4.17	83.4	57.2
July	4.37	86.1	60.9
August	3.14	84.6	58.8
September	3.23	78.4	51.8
October	3.22	66.4	41.7
November	2.53	49.5	31.1
December	2.47	37.1	21.7
AVERAGE	3.07	61.5	39.3
TOTAL	36.78		

the weather characteristics for the area is presented below. Information for this report was produced from Soil Conservation Service data (USDA, 1980).

The climate of Marshall County, influenced both by cool Canadian air masses from the north and by humid, semitropical air masses from the south, can be generally described as continental, although there is modification from the Great Lakes. The average winter temperature is 27^{o} F (-2.8^{o} C) with an average minimum winter temperature of 19^{o} F (-7.2^{o} C). The average summer temperature is 72^{o} F (22.2^{o} C) with an average daily maximum temperature of 85^{o} F (29.4^{o} C). The average relative humidity in mid-afternoon is near 60%. On most nights, however, relative humidity increases to an average at dawn of around 80%. Dew and frosts are common.

Precipitation is evenly distributed throughout the year (Figure 8). The average monthly precipitation is approximately 3.07 inches (7.79 cm). Spring and early summer rains generally exceed precipitation levels during the rest of the year and are considered reliable for ensuring excellent crop growing conditions. Average duration of storms is approximately 16.6 hours, with a minimum of 12.0 hours in June and a maximum of 22.0 hours in April. The mean annual precipitation is 36.78 inches (93.42 cm). Annual snowfall averages 36.3 inches (92.20 cm).

The highest average wind speeds are found during the spring as south-southwesterly winds average about 12 miles per hour. Winter winds are generally out of the northwest. Therefore, summer storms traverse the Lake of the Woods watershed from southwest to northeast in opposition to channel flow and overland runoff to the lake. Winter storms travel from northwest to southeast but often bring snow rather than rain. The only damaging winds arise from thunderstorms or tornadoes, although tornadoes are quite rare.

Investigation of precipitation chemistry in this study focused on plant nutrients (i.e., nitrogen and phosphorus) to quantify atmospheric loading of these elements. Although information on the subject was scarce, wet fall data were found for two monitoring stations within a reasonable distance of Lake of the Woods: Benton Harbor, Michigan and Put-in Bay, Ohio. Interpolated averages were found for total phosphorus (0.07 mg/l), nitrate (0.45 mg/l), and ammonia (1.18 mg/l). Data were unreliable for total nitrogen. Combining these averages with annual atmospheric water loading yielded estimates for atmospheric nutrient loading. Annual atmospheric loading for Lake of the Woods was calculated to be 242.8 pounds/year (110.1 kg/yr) of total phosphorus, 1,560.8 pounds/year (707.8 kg/yr) of nitrate-nitrogen, and 4,092.7 pounds/year (1,856.1 kg/yr) of ammonia-nitrogen.

It should be noted, however, that although these figures formed the basis for assessing atmospheric nutrient loading, the supporting data were gathered at considerable distances from Lake of the Woods and a large degree of uncertainty accompanies them. In particular, phosphorus concentrations in rainfall may be considerably higher in Marshall County than indicated by these figures. The intensive row crop agriculture practiced in many areas of the County tends to contribute large amounts of particle-bound phosphorus to the atmosphere in the form of dust. Such areas generally experience increased phosphorus levels in precipitation.

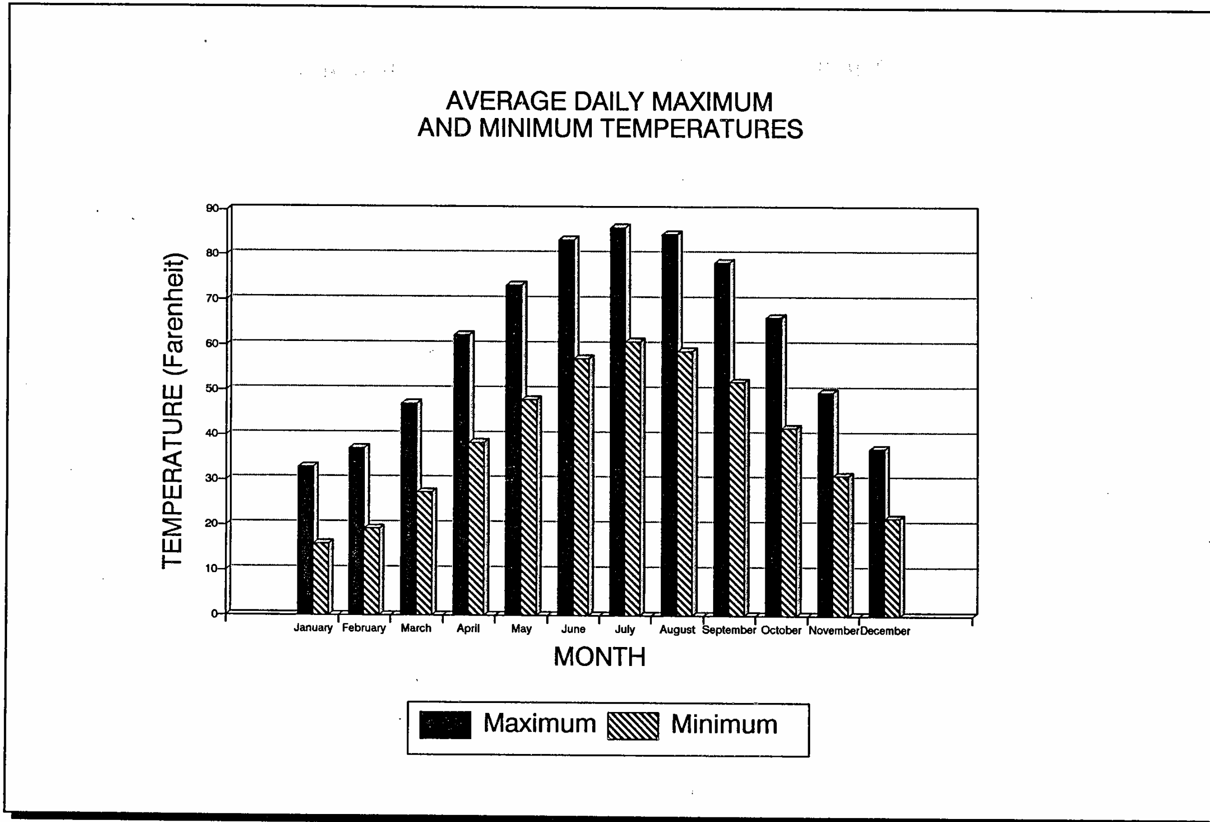

Figure 8. Monthly distribution of precipitation in the Lake of the Woods watershed.

4.2.2 Hydrology

Another "master variable" controlling the condition of water bodies is the physical layout of the drainage basin. The general topographic attributes of the catchment area influence the behavior of water once it reaches the ground. In conjunction with climate, hydrologic features affect runoff volume (i.e, mass input), velocity (i.e., erosional capacity), and timing (i.e., flood potential). Important aspects of a watershed investigation include consideration of watershed slope, geographic orientation, and drainage pattern. Characterization of hydrologic features for this study focused on three types of analyses: (1) a general description of watershed morphological attributes, (2) calculation of an approximate mass-balance water budget, and (3) calculation of hydraulic retention time.

The slope of a drainage basin has an important and complex role influencing infiltration, runoff, soil moisture, and groundwater contribution to stream flow. Slope is one of the major factors governing the time required by overland flow to reach channels where it is quickly transferred downstream (i.e, time of concentration). Greater slopes generally increase runoff velocity, thereby decreasing time of concentration. Elevated runoff velocity is also accompanied by diminished infiltration and enhanced erosional capacity. The Lake of the Woods watershed has an average slope of 1.7%, reflecting the relatively flat topography of the region. The maximum slope, 8.5%, occurs in a hilly region west of the lake between East 3D and East 4th Roads. The elevation of the basin ranges from 803 feet (245 m) near the lake to 880 feet (268 m) along the northwestern border of the watershed.

Basin orientation, often called "aspect", refers to the compass direction toward which most of the slopes in the catchment face. Since Lake of the Woods is situated southeast of its drainage area, most slopes face southeast. This orientation is important, especially in winter, because snow on these slopes is exposed to the most direct angle of solar incidence and, therefore, melts quickly. When snow melt occurs, the stored water is released, emulating the effects of small rainfall events. Gradual stream flows, fed by snowmelt, can be expected throughout the winter and early spring.

Another important characteristic of any watershed is the arrangement of the streams that drain it. The efficiency of the drainage system and, therefore, the characteristics of flood peaks are directly dependent on this attribute. Generally, if a basin is well-drained and the length of overland flow is short, surface runoff concentrates rapidly and contributes to a high flood peak. Average flows are usually low in such systems. One measure of drainage efficiency used in this study is "drainage density", the ratio of total length of perennial channels to total watershed area. This index provides an indication of basin stream coverage. The Lake of the Woods watershed has a drainage density of 4.71 miles/square mile (7.22 km/km^2) and, using this criteria alone, would be considered well-drained and prone to flash flood flows. This tendency toward flash flooding is normally mitigated by long overland flows, which are characteristic of moderate slopes. However, the flow lengths in the Lake of the Woods watershed have been shortened considerably by an extensive sub-surface drainage system (tiles) installed throughout the watershed. The general drainage pattern of the watershed tributaries can be described as dendritic.

Table 20. Components of the Lake of the Woods water budget.

ANNUALIZED RAW DATA:

ATTRIBUTE	TRADITIONAL VALUE		METRIC VALUE
Watershed Area	6054	acres	2451.0 ha
Lake Surface Area	416	acres	168.4 ha
Precipitation	36.78	inches	93.42 cm
Runoff	11.96	inches	30.38 cm
Pan Evaporation (raw)	31	inches	78.74 cm

ANNUALIZED WATER BUDGET DATA:

INPUT PARAMETER	TRADITIONAL VALUE	METRIC VALUE
Precipitation	5.56×10^{7} cubic feet	1.57×10^{6} m^3
Runoff	2.63×10^{8} cubic feet	7.45×10^{6} m^3
Groundwater[a]	0.00×10^{1} cubic feet	0.00×10^{1} m^3
TOTAL INPUTS	3.19×10^{8} cubic feet	9.02×10^{6} m^3

OUTPUT PARAMETER	TRADITIONAL VALUE	METRIC VALUE
Evaporation	4.68×10^{7} cubic feet	1.32×10^{6} m^3
Lake Outflow[b]	2.72×10^{8} cubic feet	7.70×10^{6} m^3
Groundwater[a]	0.00×10^{1} cubic feet	0.00×10^{1} m^3
TOTAL OUTPUTS	3.19×10^{8} cubic feet	9.02×10^{6} m^3

HYDRAULIC RETENTION DATA:

PARAMETER	TRADITIONAL VALUE	METRIC VALUE
Lake Volume	2.68×10^{8} cubic feet	7.60×10^{6} m^3
Net Inflow Volume	2.72×10^{8} cubic feet	7.70×10^{6} m^3
Hydraulic Retention	0.985 years (360 days)	same

[a]Assumed to be 0 due to unavailability of data.
[b]Calculated as the residual of (inputs - evaporation).

An annual water budget was computed separately for the Lake of the Woods watershed using the climatic and hydrologic data discussed above. Water budget components included information on inputs (e.g., direct precipitation, runoff, and springs) and outputs (e.g., evaporation, lake outflow, and leakage). These components are summarized in Table 20. The total calculated volume of water input annually to Lake of the Woods (i.e., the sum of the inputs from direct precipitation to the lake, runoff from the catchment, and groundwater inputs) was 3.19 X 10^8 ft^3 (9.02 X 10^6 m^3). Of this amount, 83% was attributed to runoff from the catchment (including stream flow), and 17% was attributed to direct rainfall on the lake surface. Of the outputs, lake outflow constituted 85% of the total, while evaporation accounted for 15%.

Hydraulic retention time, the ratio of lake water volume to the net annual inflow water volume, was estimated to be 0.985 years, or 360 days. Based on this calculation, the entire volume of the lake would be replaced approximately once per year. An hydraulic retention time of one year is a relatively long retention period, providing ample time for algal biomass to accumulate if there are sufficient nutrients present in the water column. From the perspective of lake restoration, Lake of the Woods is likely to have a relative slow response to a reduction in external nutrient loading based on the longer retention time.

4.2.3 Soils

The soils in Marshall County formed from glacial till, glacial outwash, alluvium, and organic material as the area was covered during successive ice-ages. Marshall County contains 36 different soil series. These series are further divided into phases that distinguish differences in slope, wetness, erosive potential, and other characteristics that affect their management. Using the Soil Survey of Marshall County (SCS, 1980) soils within the Lake of the Woods watershed were digitized and summarized using a computer gridding program. This process revealed the presence of 36 soil phases within the watershed. Three of these phases, Crosier Loam, Rensselaer Loam, and Houghton muck (drained), accounted for just over 50% of the areal soil coverage within the watershed. Table 21 summarizes the percent coverage of soil phases within the Lake of the Woods watershed.

Nearly 50% of the soils in the watershed are classified as "hydric" by the SCS. The majority of these soils are, however, drained for agricultural use. Additional information on hydric soils is included in Section 4.2.8.

Highly erodible soils comprise very little of the Lake of the Woods watershed, and only a small portion of Marshall County itself. Only 4.6% of the land (13,000 acres) in Marshall County has been classified as highly erodible (J. Pearson, pers. comm., Marshall County SWCD, 1991).

Table 21. Percent coverage of soil phases within the Lake of the Woods watershed.

Soil Phase	Percent of Total	Soil Phase	Percent of Total
Adrian Muck-drained	3.3%	Aubbeenaubbee Sandy Loam	1.4%
Brady Sandy Loam	3.8%	Bronson Loamy Sand	1.1%
Brems Sand	0.3%	Brookston Silt Loam	6.5%
Chelsea Fine Sand (6-12%)	0.3%	Crosier Loam	20.4%
Edwards Muck	0.2%	Fox Sandy Loam (0-2%)	0.1%
Gilford Sandy Loam	2.9%	Houghton Muck-ponded	0.2%
Houghton Muck-drained	13.1%	Martinsville Loam (0-2%)	0.3%
Martinsville Loam (2-6%)	0.6%	Martinsville Loam (6-12%)	0.3%
Metea Loamy Fine Sand (2-6%)	0.4%	Metea Loamy Fine Sand (6-12%)	0.2%
Milford Silty Clay Loam	0.1%	Oshtemo Loamy Sand (0-2%)	2.0%
Oshtemo Loamy Sand (2-6%)	5.5%	Oshtemo Loamy Sand (6-12%)	2.5%
Oshtemo Loamy Sand (12-18%)	0.2%	Owosso Sandy Loam	0.2%
Palms Muck-drained	2.8%	Pinhook Sandy Loam	1.1%
Rensselear Loam	19.2%	Riddles Sandy Loam (0-2%)	0.6%
Riddles Sandy Loam (2-6%)	4.2%	Riddles Sandy Loam (6-12%)	0.3%
Tyner Loamy Sand (0-2%)	0.2%	Tyner Loamy Sand (2-6%)	0.2%
Tyner Loamy Sand (6-12%)	0.6%	Wallkill Silt Loam	0.1%
Washtenaw Silt Loam	0.1%	Whitaker Loam	4.5%

4.2.4 Land Use

Perhaps the most influential factor governing the longevity and quality of a surface water body is the nature of land use in the drainage basin. Land use categorization within the Lake of the Woods watershed was critical in determining input parameters for the AGNPS model. The 16 land use categories identified and corresponding areal coverages are listed in Table 22. A color-coded land use map is presented in Figure 9. The primary land use within the Lake of the Woods watershed was row crop agriculture, accounting for nearly 64% of the total area. Blocks of row crops were dispersed fairly uniformly throughout the watershed, although the area directly north and west of the lake contained the highest densities of agricultural property. Non row crop fields cover 8.6% of the watershed. Water, comprised mainly of the lake itself, covers 9.1% of the watershed. Included in the water category are ponds, streams, and ditches. Forested areas, which may serve as sediment and nutrient buffers to receiving waters, encompass 7.2% of the area. Residential use categories cumulatively accounted for nearly 6% of the area. Nearly all of the residential developments were considered low density, with the largest concentrations occurring along the eastern perimeter of Lake of the Woods. Although it comprises a relatively small percentage of the total watershed, the proximity of population concentrations to the lake makes their impact a significant one. Increased lawn fertilizer runoff, septic and storm sewer infiltration, and loss of lake-associated wetlands are characteristic of near-shore residential areas.

Table 22. Land use areas/percentages for the Lake of the Woods Watershed.

WATERSHED CATEGORY	WATERSHED AREA acres / hectare	PERCENT
Water	551.8 / 223.4	9.11
Wetlands	21.9 / 8.9	0.36
Forest	434.4 / 175.9	7.18
Recreational	81.0 / 32.8	1.34
Pasture	158.2 / 64.1	2.61
Row Crops	3863.7 / 1564.3	63.82
Non Row Crops	521.4 / 211.1	8.61
Orchard	0.0 / 0.0	0.00
Feedlot	0.0 / 0.0	0.00
Low Density Residential	358.2 / 145.0	5.92
High Density Residential	1.6 / 0.7	0.03
Commercial	6.8 / 2.8	0.11
Institutional	0.0 / 0.0	0.00
Excavation/Gravel	26.0 / 10.5	0.43
Landfill	4.9 / 2.0	0.08
Open/Fallow Land	23.8 / 9.7	0.39
TOTALS	6054.0 / 2451.0	100.00

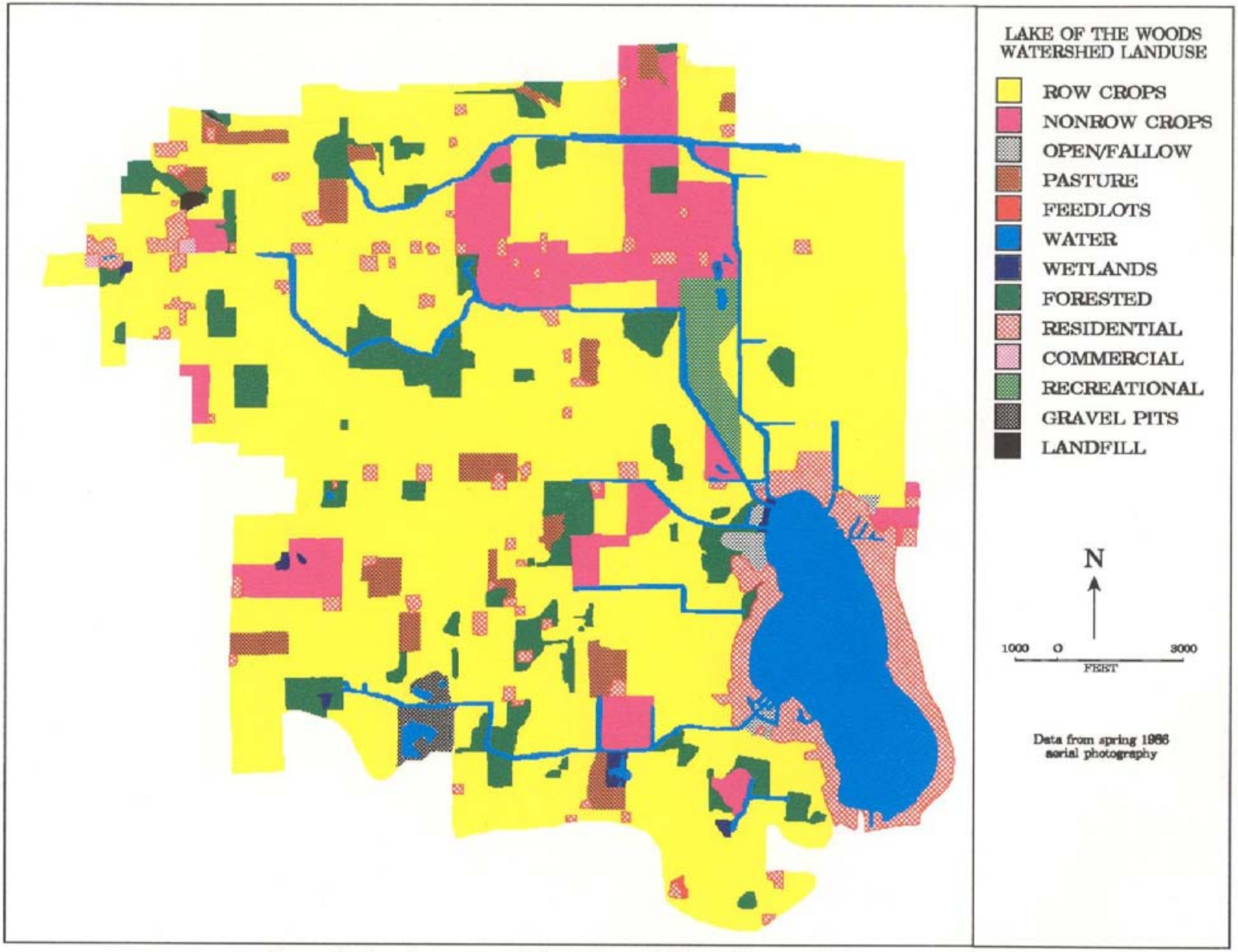

Figure 9. Land use map of the Lake of the Woods watershed.

4.2.5 Sediment/Nutrient Modeling

Areas within the Lake of the Woods watershed contributing disproportionately greater amounts of sediments and nutrients were identified with the AGNPS model. In using this model, it was necessary to divide the watershed into a grid of equally sized areas, called "cells". The watershed outline, lake, and streams, with the AGNPS grid overlay, are displayed in Figure 10. For the Lake of the Woods

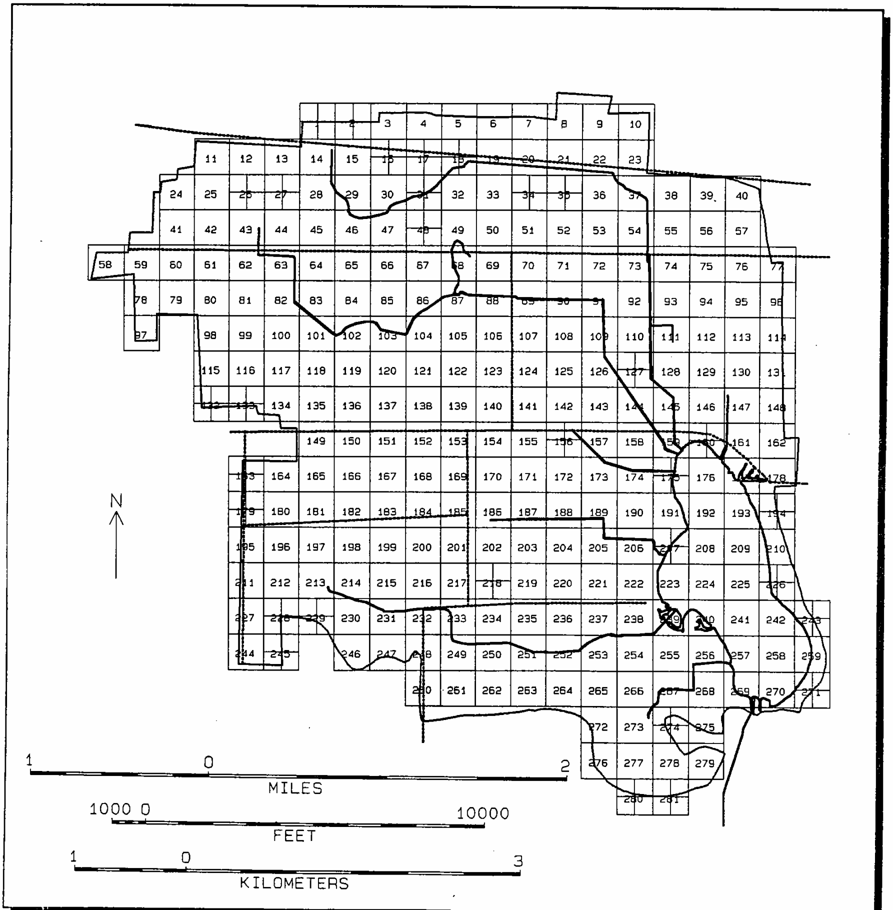

Figure 10. Layout of Lake of the Woods watershed cells used in the AGNPS model.

watershed, the optimum cell size was determined to be 25 acres. Data characterizing the physical features of the cells were utilized by the model to describe the sediment and nutrient contributions of each cell.

Four categories of AGNPS output were evaluated in describing the pertinent export features: (1) sediment yield; (2) cell erosion; (3) nutrient loading; and (4) hydrology. Some of the physical characteristics associated with cells identified by the AGNPS model as "hotspots" for sediment and nutrient production or transport are summarized in Table 23. The following discussion summarizes the AGNPS output from

Table 23. Summary of physical characteristics of cells determined by the AGNPS model to exhibit high sediment or nutrient export values.

Cell #	Land Slope	Dominant Soil Texture	Average K-value[1]	Dominant Landuse	Notable Cell Export(s)
38	1.0%	loam	0.19	rowcrops	soluble N-P/runoff
39	1.0%	muck-drained	0.12	rowcrops	soluble N-P/runoff
56	1.0%	loam	0.14	rowcrops	soluble N-P/runoff
66	1.3%	loam	0.32	rowcrops	soluble N-P
75	1.0%	loam	0.26	rowcrops	soluble N-P
89	1.0%	loam	0.33	rowcrops	sediment yield
90	1.0%	loam	0.28	rowcrops	sediment yield
126	1.2%	muck-drained	0.02	rowcrops	sediment yield
127.300	1.0%	muck-drained	0.02	recreation	sediment yield
135	1.0%	loam	0.27	rowcrops	soluble N-P/runoff
138	6.3%	sandy loam	0.25	rowcrops	sediment N-P/erosion
144	1.1%	muck-drained	0.13	crops	sediment yield
147	1.2%	muck-drained	0.12	rowcrops	runoff
159	1.4%	muck-drained	0.14	rowcrops	sediment yield
217	5.0%	loamy sand/loam	0.23	rowcrops	sediment & soluble N-P
218.300	8.5%	fine sand	0.18	rowcrops	erosion
218.400	5.7%	loam/fine sand	0.17	rowcrops	sediment N-P
246	3.2%	loamy to fine sand	0.22	rowcrops	runoff
274.100	5.7%	loamy sand	0.37	rowcrops	erosion
279	5.3%	loam	0.33	rowcrops	erosion

[1]K-value indicates the susceptibility of a soil to sheet and rill erosion by water.

each of the four categories (i.e., sediment yield, cell erosion, nutrient loading, and hydrology).

Sediment Yield and Erosion. Sediment yield from each AGNPS cell is the amount of sediment, in tons, that leaves a cell at its downstream edge. This quantity represents not only the sediment generated inside the cell but also sediment generated in upstream cells. It is important to note that AGNPS also accounts for sediment deposition within a cell if appropriate conditions exist. Therefore, sediment yield is calculated as the sediment generated in the cell, plus the sediment entering from cells upstream, minus the sediment deposited in the cell.

Cell erosion refers to the amount of sediment that is produced within an individual cell rather than the cumulative amount passing through the cell. It is useful in identifying the cells that experience the greatest amount of internal erosion. The most important factors contributing to high erodibility within a given cell are soil erodibility (i.e., K-factor) and land slope. Land use, water flow velocity, and the presence/absence of defined stream channels within a cell also influence erosion. Areas of intense rowcrop agriculture generally produce decidedly higher erosion losses than areas consisting of forests or wetlands. It was necessary to examine cell erosion and sediment yield in order to recognize source areas separately from conduit (i.e., "flow-through") areas. Because management options exist for both source and downstream sediment control, the distinction is often an important one. Results of the model runs are discussed below. Watershed cells with high sediment yield and high cell erosion are displayed in Figures 11 and 12, respectively.

Sediment Yield: The total sediment yield into Lake of the Woods during the modeled storm was 504.8 tons (458.1 MT). The amount of sediment yield from each cell ranged from no yield to nearly 266 tons (241 MT). The cell with the highest sediment yield, 265.8 tons (241.2 MT), to the lake was cell #159. This cell is located along the lake's northwest shore and contains the mouths of both the Walt Kimble and Martin Ditches. While the sediment generated within cell #159 was only 2.5 tons (2.3 MT), the amount of sediment entering the cell from upstream sources was significant. The cell is traversed, from the northwest and north by Martin and Walt Kimble Ditches, respectively. The total area draining towards cell #159 is 3,188 acres (1291 ha), over ½ of the entire watershed. The majority of the drainage area for this cell is used for agricultural purposes.

Other cells located along these stream corridors also exhibited high sediment yields. A total of six additional cells were found to contribute greater than 155 tons (141 MT) of sediment. All six are crossed by Martin Ditch and situated east of North Kenilworth Road and northwest of the lake. Cell #89, situated just east of North Kenilworth Road and south of Highway 6, contributed 179 tons (162 MT) of sediment. Cells #126 and #127.300 (primary cell #127, subcell 300), transported 165 tons (150 MT) and 162 tons (147 MT), respectively, of sediment during the simulated storm. These cells are situated along a golf course and fields northwest of the lake at the point where Martin Ditch bends southeast towards Lake of the Woods. Cell #90, located directly east of cell #89, exhibited a sediment yield of 159 tons (144 MT). A sediment yield of 158 tons (143 MT) was found in cell #144, situated north of East 3D Road and bisected northwest to southeast by Martin Ditch. Collectively, these cells constituted the area of highest sediment load to Lake of the Woods. While the relative sediment contributions of individual cells were not remarkable, the cumulative sediment drainage through this area was significant. It is important to note, however, that the location of these cells within the overall drainage scheme of the lake, rather than their physical characteristics, explains the high sediment yields predicted by AGNPS. Specifically, the modeled sediment yield from these cells was the result of 4 factors:

1) A large sub-basin that channeled runoff through the stream
2) Land uses conducive to sediment export in the sub-basin
3) Moderately erodible soils within the sub-basin
4) A paucity of sediment depositional areas (i.e., wetlands, forests, and vegetated buffers) along the western reaches of Martin Ditch.

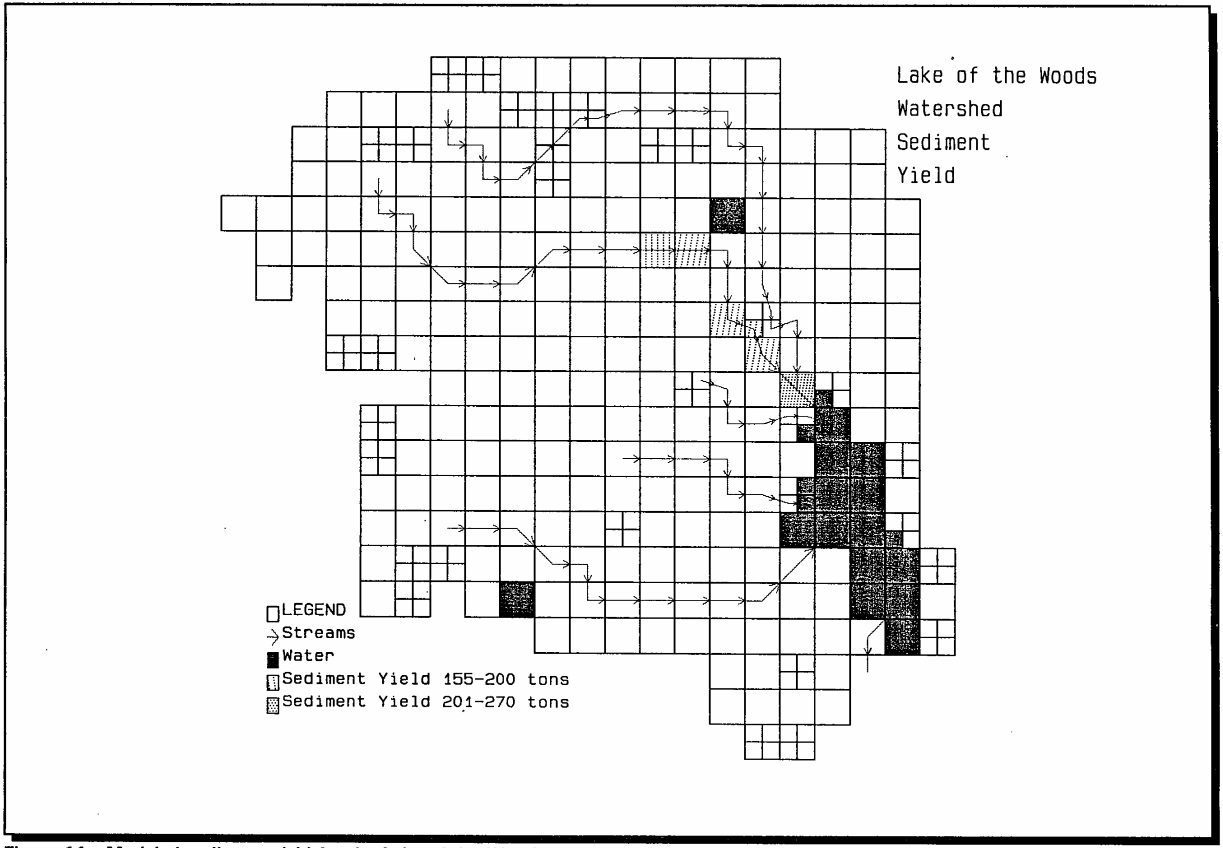

Figure 11. Modeled sediment yield for the Lake of the Woods watershed.

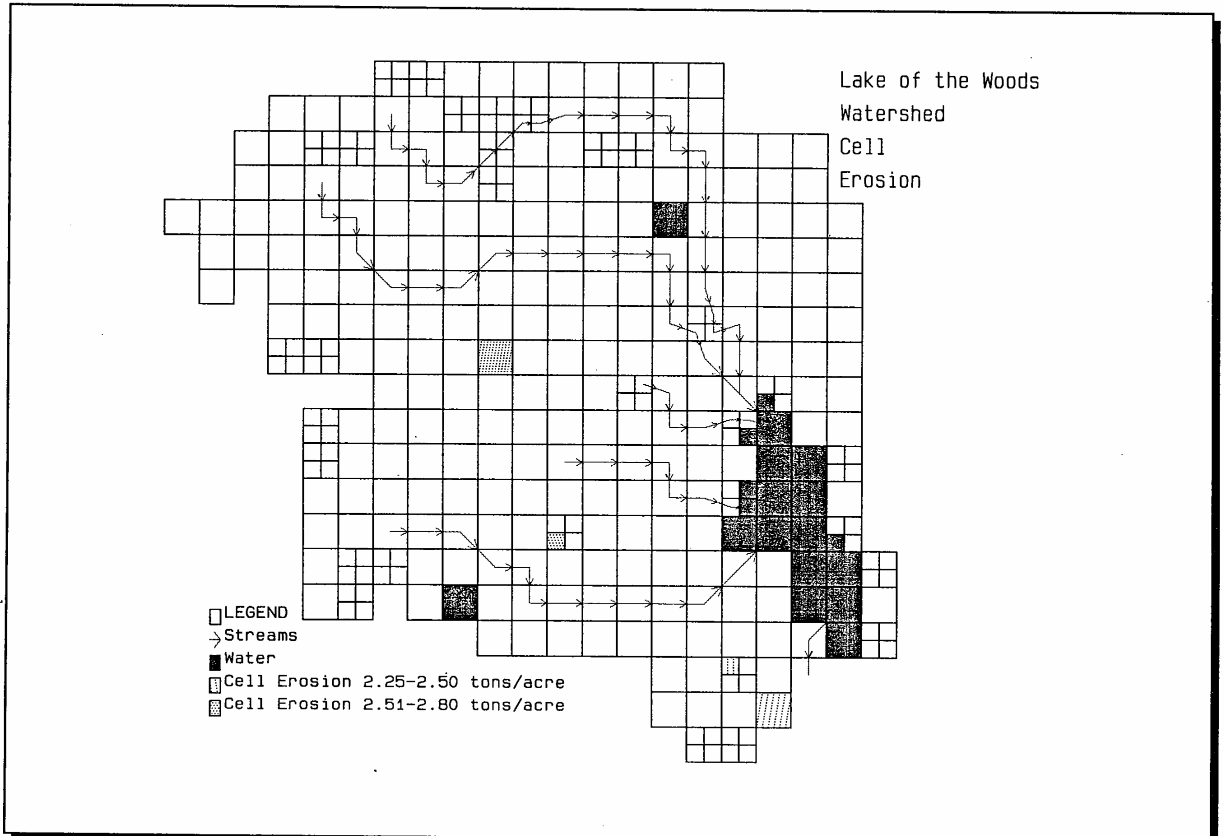

Figure 12. Modeled cell erosion for the Lake of the Woods watershed.

Cell Erosion: Cell erosion figures generated by the AGNPS model for the 2-year, 24-hour storm ranged from no sediment production to 2.76 tons/acre (6.19 MT/ha). Cells exhibiting little or no erosion were those areas consisting of water, wetlands, or undrained muck soils. The highest rate of erosion was found in cell #138. This cell is located on the north side of East 3D Road approximately 2600 feet west of the intersection of East 3D and North Kenilworth Roads. The soil type in this cell is over 65% Riddles sandy loam, with 6 to 12% slopes. The land use within this area consisted of 87.5% row crop fields and 12% pasture. In this instance, the land slope (6.3%), the land use, and the soil erodibility (K = 0.25) all contributed to the high sediment production within this cell. Cell #218.300 (main cell 218, subcell 300), was responsible for 2.51 tons/acre (5.62 MT/ha) of sediment erosion. This 6.25-acre cell is located just northeast of the intersection of East 4th Road and Kenilworth Road. The soils in this subcell were 72% Chelsea fine sand, with 6 to 12% slopes. Land use consisted of 92% row crop fields. Cells #274.100 and 279, situated southwest of the lake north of East 5th Road, both had erosion production rates of approximately 2.30 tons/acre (5.15 MT/ha). The land use within these cells was almost entirely row-crop agriculture. The soils within these cells were mostly loams and loamy sands with land slopes in excess of 5.0%. The erodibility factors (K-values) for cells 274.100 and 279 were quite high at 0.37 and 0.33, respectively.

Nutrient Loading

The AGNPS model supplied estimates for nitrogen and phosphorus concentrations in runoff from the watershed. Values were produced for both sediment-bound and soluble forms of the nutrients. In general, areas exhibiting high outputs of sediment-bound nitrogen will also exhibit high outputs of sediment-bound phosphorus. This observation is also true for the soluble components of nitrogen and phosphorus. For this reason, the following discussion of nutrient inputs is presented as an analysis of nutrient inputs to the lake by the respective sediment-bound and soluble form. The model furnished predictions for the entire watershed and for individual cells. Modeled results for soluble nitrogen and phosphorus are presented in Figures 13 and 14. Sediment-bound nitrogen and phosphorus results are displayed in Figures 15 and 16.

Using cumulative data generated by the AGNPS model for those cells bordering Lake of the Woods, it was possible to calculate the total phosphorus and nitrogen (i.e., soluble plus sediment bound) loading to the lake during the design storm. Total nitrogen loading was 7.08 tons (6.43 MT). Approximately 84% of this amount, 5.97 tons (5.42 MT), was in the form of soluble nitrogen. Total phosphorous loading to Lake of the Woods was determined to be 1.76 tons (1.60 MT). Soluble phosphorus accounted for approximately 68% of this amount. The generally moderate slopes throughout the watershed serve to minimize potential sediment erosion during a storm event, thereby diminishing the sediment-bound nutrient input. Sediment-bound nutrients would therefore be less important than the soluble nutrient inputs. Additionally, hydric soils used for agriculture may be susceptible to high soluble nutrient exports due to rapid runoff caused by low permeabilities. Inundated and seasonally unvegetated soil surfaces and fertilization also result in high soluble nutrients in runoff. In addition, the rapid storm runoff from these lands allows less time for soils and vegetation to assimilate soluble nutrients.

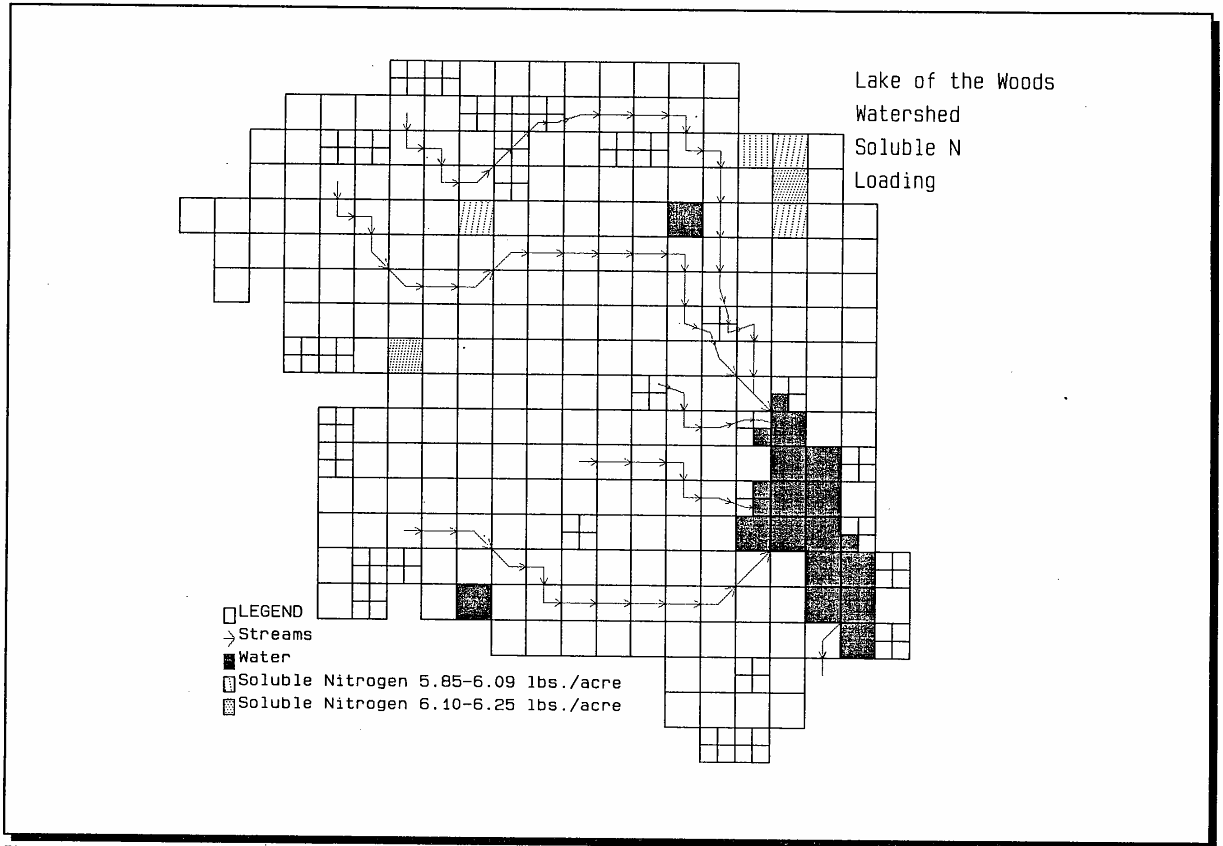

Figure 13. Modeled soluble nitrogen loading for the Lake of the Woods watershed.

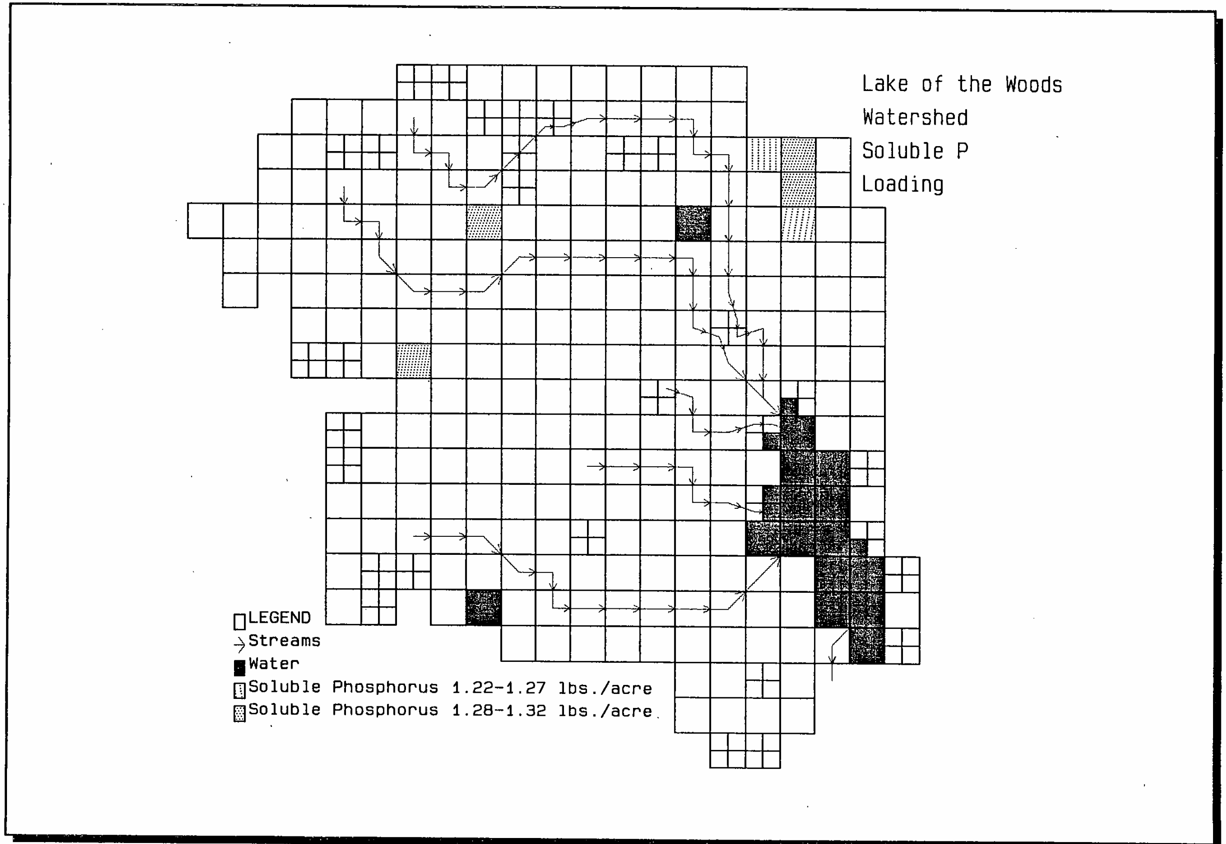

Figure 14. Modeled soluble phosphorus loading for the Lake of the Woods watershed.

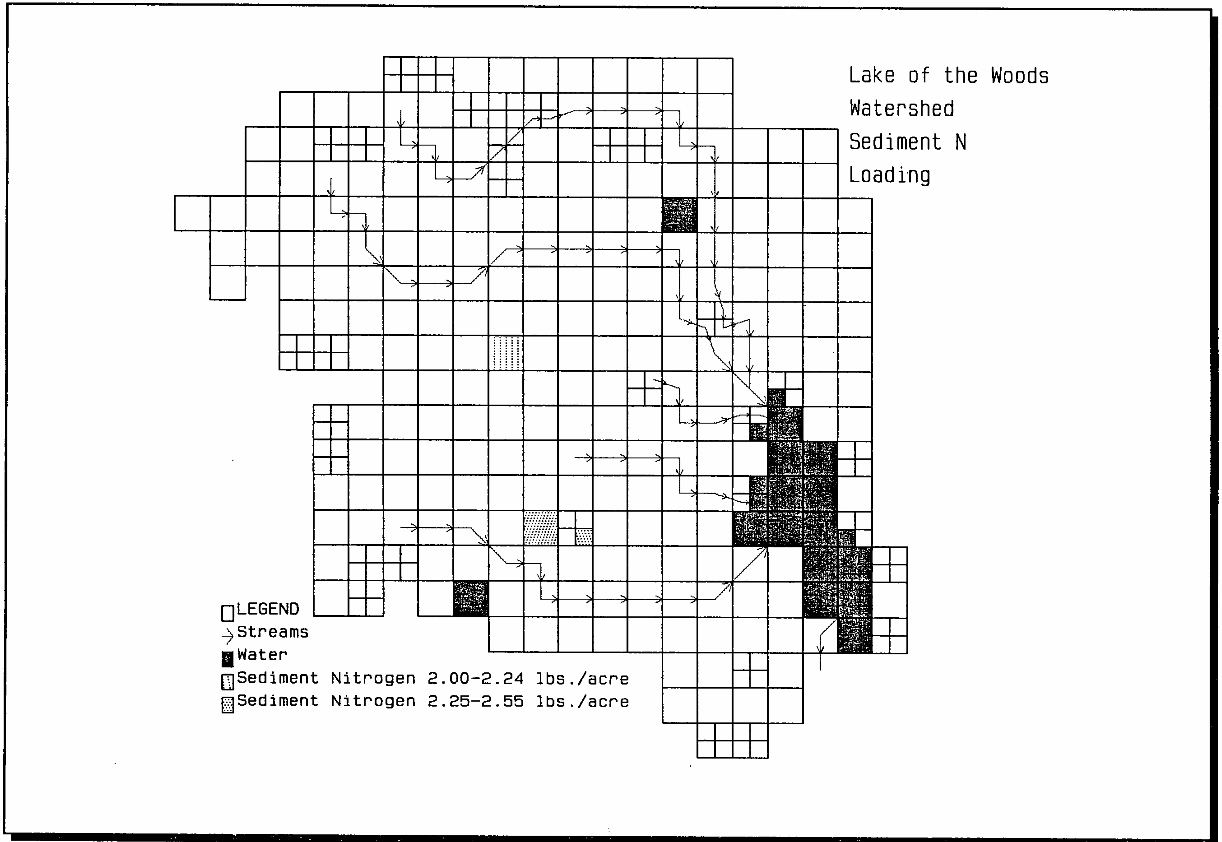

Figure 15. Modeled sediment-bound nitrogen loading for the Lake of the Woods watershed.

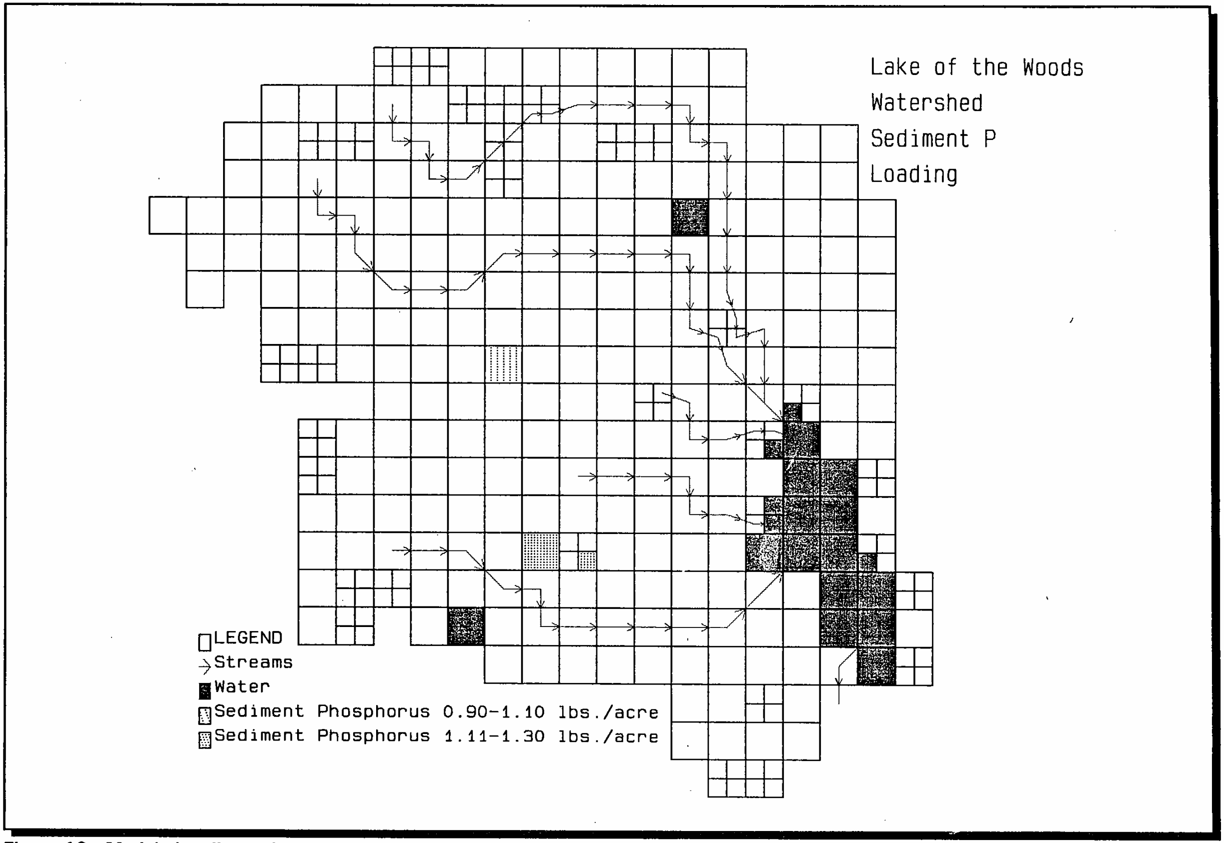

Figure 16. Modeled sediment-bound phosphorus loading for the Lake of the Woods watershed.

The concentration of soluble nitrogen exported from individual cells ranged from no export to 6.23 pounds/acre (6.98 kg/ha). The range of values generated for soluble phosphorus was 0.0 lbs/acre to 1.31 lbs/acre (1.47 kg/ha). The six cells that were identified by the model as the highest exporters of soluble nutrients are listed in Table 24. Cell #135, located on the east side of North Linden Road just north of

Table 24. AGNPS cells with the highest soluble nutrient exports.

Cell #	Soluble Nitrogen (lbs/acre)/(kg/ha)	Soluble Phosphorus (lbs/acre)/(kg/ha)	Location
135	6.23 / 6.98	1.31 / 1.47	Intersection of East 3D and N. Linden Road
56	6.18 / 6.92	1.31 / 1.47	North of Hwy. 6, east of Walt Kimble Ditch
39	6.07 / 6.80	1.29 / 1.44	South Balt. & Ohio RR, east Walt Kimble Ditch
66	6.06 / 6.79	1.28 / 1.43	Bisected by Hwy. 6, west of North King Road
75	5.96 / 6.68	1.25 / 1.40	South of Hwy. 6, east of Walt Kimble Ditch
38	5.86 / 6.56	1.24 / 1.39	South Balt. & Ohio RR, east Walt Kimble Ditch

its intersection with East 3D Road, exported the highest amount of soluble nitrogen. In this cell, all of the nitrogen exported was generated within the cell. Land use was 96% row crops and soils were mostly Brady sandy loam with Brookston loam and Crosier loam. The other five cells identified by the model, cells #38, #39, #56, #66, and #75, were also predominantly agricultural. Soils were mostly loamy and classified as hydric, although it is assumed that these areas are extensively drained to permit agricultural activities. Moderate slopes, generally 1.0%, were observed within each cell.

The amount of sediment-bound nutrients exported by an area is strongly correlated to the quantity of sediment exported. Cells with high sediment-bound nutrient exports generally have relatively steep slopes, erodible soils, and lack features conducive to sediment deposition. Sediment depositional areas may include topographic features (e.g. depressions) or vegetative features (e.g. forests and wetlands) that reduce storm runoff and trap sediments. The AGNPS model recognizes these areas by various cell characterizations including slopes and soil textures. Sediment-bound nitrogen exported from individual cells within the Lake of the Woods watershed ranged from 0.0 pounds/acre (0.0 kg/ha) to 2.54 pounds/acre (2.84 kg/ha). Conveyance of sediment-bound phosphorus ranged from 0.0 pounds/acre to 1.27 pounds/acre (1.42 kg/ha). The three cells that were identified by the model as the highest exporters of sediment-bound nutrients are listed in Table 25. The highest value for both nutrients was observed in Cell #217, located on the north side of East 4th Road and the west side of North Kenilworth Road. The soils in this cell are approximately 60% Oshtemo loamy sands and 30% Rensselaer loam with an average slope of 5.0%. Land use within this cell is 89% row crop agriculture. This cell also exhibited generally high levels of soluble nutrient export. Cell #218.400, the south east quadrant of the cell directly east of cell #217, exported 1.21 pounds/acre (1.36 kg/ha) of sediment-bound phosphorus and 2.42 pounds/acre (2.71 kg/ha) of sediment-bound nitrogen. Cell #138 exported 0.93 pounds/acre (1.04 kg/ha) of sediment-bound phosphorus and 1.87 pounds/acre (2.09 kg/ha) of sediment-bound nitrogen. Both cells were greater than 95% agricultural. Soils in cell #218.400 were predominantly loamy and fine sand with an average

Table 25. AGNPS cells with highest sediment-bound nutrient exports.

Cell #	Sediment Nitrogen (lbs/acre)/(kg/ha)	Sediment Phosphorus (lbs/acre)/(kg/ha)	Location
217	2.54 / 2.84	1.27 / 1.42	Northwest of intersection of East 4th and N. Kenilworth Roads
218.400	2.42 / 2.71	1.21 / 1.36	Northeast of intersection of East 4th and N. Kenilworth Roads
138	1.87 / 2.09	0.93 / 1.04	North of East 3D, between N. Linden and Kenilworth Roads

slope of 5.7%. Cell #138 contained mostly Riddles sandy loam with an average slope of 6.3%.

Hydrology

The AGNPS model was also used to examine hydrologic inputs to Lake of the Woods. Results for the simulated storm are presented below. In general, the model identifies cells that contain significant quantities of water (i.e., lake cells) as those with the highest levels of runoff. This observation is correct for areas that are completely saturated and therefore incapable of absorbing additional runoff. Most cells containing ponds, lakes, and wetlands may, however, store runoff during a storm event. For this reason, the high runoff values predicted for lake cells may not actually be cause for concern within the Lake of the Woods watershed. Watershed cells producing high runoff, that did not contain large areas of water, are summarized in Table 26 and displayed in Figure 17. Hydrologic input to Lake of the Woods for the modeled storm was estimated to be 2.28×10^7 ft^3 (6.46×10^5 m^3). The area that generated the greatest volume per acre, 6,207.3 ft^3 (175.8 m^3), was cell #147. Cell #147 is situated along the east side of the

Table 26. AGNPS cells generating the highest levels of stormwater runoff.

Cell #	Cell Runoff (ft^3/acre) / (m^3/acre)	Location
147	6207.3 / 175.8	Northeast of Lake of the Woods along unnamed tributary
38	5916.9 / 167.6	South of Balt. & Ohio RR, east of Walt Kimble Ditch
39	5916.9 / 167.6	South of Balt. & Ohio RR, east of Walt Kimble Ditch
56	5916.9 / 167.6	North of Hwy. 6, east of Walt Kimble Ditch
135	5916.9 / 167.6	Northeast of intersection of East 3D and N. Linden Road
246	5916.9 / 167.6	Just northeast of bend between West 4A Road and East 4B Road

unnamed tributary approximately 1,400 feet northeast of Lake of the Woods. It is utilized primarily for rowcrop agriculture (83%). This cell was composed of mostly hydric soils including Houghton muck, and Pinhook and Gilford sandy loams with an average slope of 1.2%. Five other cells generated 5,916.9 ft^3 (167.6 m^3) per acre. The cells exhibiting this level of runoff were cells #38, #39, #56, #135, and #246. Land use within these cells, is over 95% rowcrop agriculture. The high rate of runoff from these

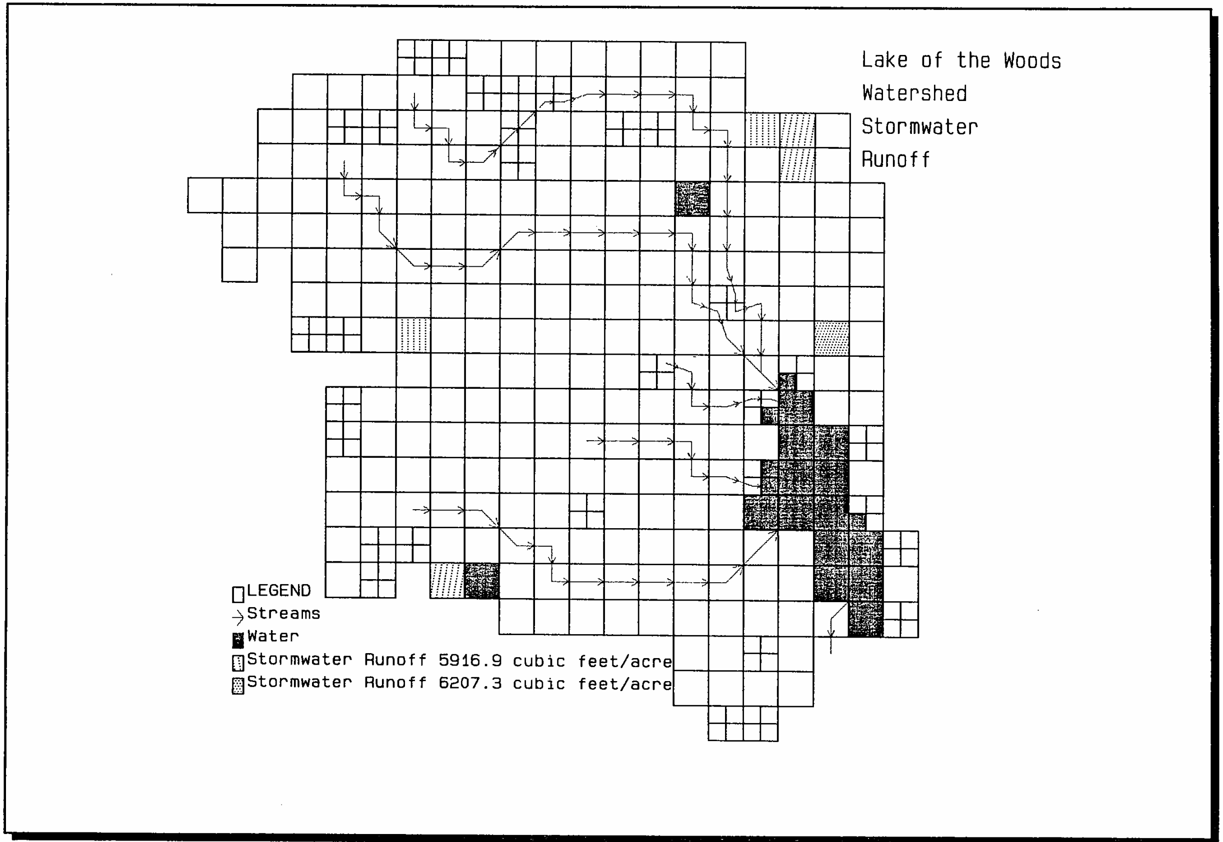

Figure 17. Modeled cell runoff for the Lake of the Woods watershed.

cells is probably a result of runoff from agricultural lands associated with seasonally inundated soils.

4.2.6 Septic System Survey

A sanitary sewer system that would serve residents along the entire shoreline of Lake of the Woods is tentatively scheduled for construction this year. It is anticipated that this system will be 100% effective in eliminating septic system inputs from lakeshore residences. However, prior to installation of this system, an analysis was conducted to estimate the current phosphorus contribution from septic systems to the lake. A second objective of the analysis of septic phosphorus contributions was to determine the percentage of septic loading relative to the total annual phosphorus loading to Lake of the Woods. The assumptions required for this component of the Feasibility Study are listed below. Further descriptions of these assumptions are presented in subsequent text.

- The majority of residences are full-time (year-round) and occupied approximately 90% of the year. The remaining residences are seasonal and occupied 50% of the year.
- Occupied housing units are primarily greater than or equal to 8.4 years old.
- The age of the septic system is the same as the age of the home.
- Hydric soils adjacent to the lake are primarily saturated, with water tables at or near the surface for significant portions of the year.
- The average person produces 169 liters (44.6 gal.) of wastewater per day.
- The phosphorous concentration in that wastewater is 5 mg/l.
- The tank portion of the septic system is regularly maintained and retains a constant 42.5% of the phosphorus entering it for the life of the system.

The input of phosphorus from septic fields located in the vicinity of a lake is often an important source of phosphorus, particularly if the systems are constructed in poorly drained soils with frequent high water tables. Factors that influence nutrient export from septic systems to a nearby surface water body include: (1) capacity of leach field soils to attenuate (absorb) nutrients; (2) distance between leach fields and the lake; (3) number of people using septic systems; and (4) per-capita inputs to septic systems. The attenuation capacity of the soil is the first important factor influencing the nutrient load from septic systems. This value can be represented by a "nutrient retention coefficient" that ranges from 0.0 (no retention) to 1.0 (complete retention) and indicates percent of the total septic input immobilized by a septic tank/leach field combination. Retention coefficients are influenced by soil drainage, permeability, slope, soil type, and soil pH. System age, maintenance levels, rainfall frequencies, and uptake by vegetation also affect attenuation.

Homes located along the perimeter of Lake of the Woods are mostly situated within a band of Rensselaer loam. Seasonal high water tables are at a depth of 0.5 to 1.0 feet. Hydric soils are poor choices for leach fields because soil water saturation results in anoxic conditions that limit the processes that bind nutrients. Soils below the water table exhibit a 50% decrease in phosphorus adsorption (University of Michigan Biological Station, 1974). In addition, the high water table associated with these soils tends to "flush" waste materials directly into adjacent bodies of water before they can be bound to soil particles. The Marshall County Soil Survey lists limitations to septic tank absorption fields as *severe* in Renesselaer loam due to ponding and slow percolation. The severe classification indicates that soil properties or site features are so unfavorable or so difficult to overcome that special design, significant increases in construction costs, and possibly increased maintenance are required.

A limited number of residences situated adjacent to Lake of the Woods were constructed within pockets of other soils including Bronson loamy sand, Brady sandy loam, Gilford sandy loam, and Adrian muck. All of these soils were classified "severe" (the worst categorization) for construction of septic systems by the Marshall County Soil Survey.

There is a direct relationship between the age of a septic system and its capacity to retain phosphorus. As a system becomes older, the nutrient-binding sites of drain field soils become saturated and are less able to attenuate nitrogen and phosphorus. Often, however, records reflecting the age of septic systems are not available and surrogate figures must be used. For the purposes of this study, septic system ages were assumed to be the same as the ages of the residences they served. Construction dates for homes bordering Lake of the Woods were incomplete. However, local correspondence and visual examination revealed that the majority of lakeside homes were at least 20 years old.

Hill and Frink (1974) investigated the longevity of septic systems in various soil types and defined the "half-life" of a septic system as the average number of years required for the cumulative failure rate (for the total population of septic systems) to reach 50%. The researchers found that the half-life for all glacially-derived soils was 27 years. For poorly-drained soils, the half-life was determined to be 25 years. Discussions with the Marshall County Health Department (MCHD) suggested that a more realistic estimate of the entire life of systems in the hydric soils along Lake of the Woods would be considerably less than 25 years, perhaps as low as 2-5 years. The MCHD reported the results of a study estimating that the county-wide average life of a septic system was 11.75 years (half-life=5.88 years). Given the high water tables associated with lake residences, an adjusted half-life value, using a low estimate of 2.5 years and a high estimate of 5.88 years, was used. The calculated half-life of septic systems impacting Lake of the Woods was 4.1875 years. Assuming a linear relationship between the age of a system and the amount of phosphorus retained, new systems located in Marshall County glacially-derived soils would attenuate 100% of the phosphorus entering them, 5.88 year old systems would attenuate 50% of the phosphorus, and 11.75 year old systems would attenuate 0% of the phosphorus. Similarly, new systems in hydric soils along Lake of the Woods would retain 100%, 4.1875 year old systems would retain 50%, and 8.4 year old systems would retain 0%.

It should be noted that approximately 42.5% of the phosphorus entering a septic system is removed in the septic tank before the wastewater reaches the drain field (Reckhow et al., 1980; Sawheny and Hill, 1975; Bache and Williams, 1971). Because phosphorus removal processes in septic tanks involve physical settling, the retention efficiency is assumed to remain constant over time, given normal system care. Understanding that 42.5% of the phosphorus entering septic systems is removed in the septic tank, it is reasonable to conclude that the remaining 57.5% enters the drain field. Therefore, the phosphorus retention figures calculated for soils are applied to only 57.5% of the total phosphorus produced in households.

Distance between septic systems and the water body is the second important factor in determining septic impacts to a lake. Generally, as the distance between a water body and a septic system increases, the amount of nutrients reaching the water body from the system decreases. For Lake of the Woods, only those systems situated between Lakeshore Drive and the lake were evaluated for septic loading.

The number of people using septic systems in the watershed is the third important factor in determining septic loading to a lake, and can be represented by a "capita-year" figure. This value combines estimates of permanent and seasonal populations, the number of septic systems used, and the fraction of the year the systems are used. A capita-year is essentially the average number of residents per dwelling unit, multiplied by the number of dwelling units, multiplied by the fraction of a year the residents are home.

Capita-years for Lake of the Woods were calculated using data supplied by the US Census Bureau in Chicago. An interview with officials in that office revealed that the average household in Marshall County, in 1990, contained 2.74 residents. Because reliable data for seasonal occupancy of the dwellings around the lakes were unavailable, it was assumed that 90% of the residences were year-round and 10% were seasonal. Full-time residents were assumed to spend 90% of the year, 329 days, in their home. This factor allows for vacations, weekends away, and other periods in which the septic system was not in use. Seasonal residents were assumed to reside at Lake of the Woods for an average period of six months. The capita-year figures used in this study are presented in Table 27.

Table 27. Capita year data for Lake of the Woods.

Residency	Number of Dwellings	Number of Residents[a]	Time at Home[b]	Capita Years
Full	455	1246.7	90%	1122.0
Seasonal	51	139.8	50%	69.9

[a] Number of residents = number of dwellings * number of residents per dwelling (i.e., 2.74).
[b] Time at home = fraction of year residents are at not on vacation, extended trips, etc.

The fourth important factor influencing septic loading is per-capita nutrient input to septic systems. This value is simply the nutrient mass, per capita, per year that enters a septic system and is the aggregate of inputs from toilets, showers, basins, laundry rinse, and other household waste water. It is often represented by an export coefficient in kg/capita-year. A review of the literature revealed that the average person produces 44.6 gallons (169 l) of waste water per day (Chan, 1978; Brandes, 1977; Otis et al., 1974; Bouma et al., 1972; Feth, 1966; Preul, 1964). An intermediate phosphorus concentration for domestic wastewater was found to be 8 mg/l (Metcalf and Eddy, 1979). Two studies conducted in Indiana on raw sewage phosphorous concentrations found 1973-1974 concentrations of between 4.5 mg/l and 5.5 mg/l (correspondence with John Winters, IDEM, 1990). Therefore, an average phosphorous concentration of 5.0 mg/l was selected for this evaluation. Using this concentration, annual total phosphorus production was determined to be 0.68 pounds per capita (0.31 kg/capita).

Total phosphorus production and loading, by households adjacent to Lake of the Woods, is presented in Table 28 along with values for septic tank retention, and leach field retention. Under current conditions, Lake of the Woods receives approximately 466.0 pounds (211.3 kg) of total phosphorus from septic systems annually.

Table 28. Total phosphorus production/retention by household for Lake of the Woods.

Residency	Household P Production[1]	Septic Tank Retention[2]	Leach Field Retention[3]	Total P Export to Lake[4]
Full year	763.0/ 346.0	324.3/ 147.1	0.0/ 0.0	438.7/ 198.9
Seasonal	47.5 / 21.6	20.2 / 9.2	0.0/ 0.0	27.3/ 12.4
Totals	810.5/ 367.6	344.5/ 156.3	0.0/ 0.0	466.0/ 211.3

1. Household P = annual P x capita years
2. Septic tank retention = household P x 0.425
3. Leach field retention = 0; average age of systems >20 years (see text)
4. Total P export = household P - septic tank retention

NOTE: Estimates reflect annual figures for total phosphorus (lbs/kg).

For comparison purposes, the 1982 Feasibility Study (Senft and Roberts, 1982) reported that lakeshore septic systems contributed 225 kg of phosphorus per year to Lake of the Woods, only six percent greater than the value determined during this study. The percentage of the total annual phosphorus loading generated by septic systems is discussed in the following section.

4.2.7 Annualized Phosphorus Loading

External phosphorus loading to Lake of the Woods from its watershed was quantified in the preceding AGNPS modeling section (Section 4.2.5). Septic system phosphorus loading to the lake was determined based on the analysis described in Section 4.2.6. Atmospheric inputs are discussed with climate data in Section 4.2.1. While the AGNPS model results are considered useful in detecting areas of disproportionately high phosphorus loading, calculated loadings are for a single storm event rather than on an annual basis. In addition, AGNPS does not predict in-lake nutrient concentrations. To provide an annualized estimate of phosphorus loading to the lake from each of the land use categories identified, and to determine the relative contribution of septic systems to total phosphorus loading, the input-output model LAKEPHOS was applied to the Lake of the Woods watershed.

Solutions provided by input-output models are usually based on the principle of conservation of mass (i.e., matter is neither created nor destroyed) and are described through differential equations. Simply put, the net change in the concentration of a given contaminant equals the existing concentration plus any inputs minus any losses over a discreet period of time. For prediction of in-lake phosphorus concentrations, this relationship can be expressed as:

$$P = \frac{L}{v_s + q_s} \tag{1}$$

Where:

P = lake phosphorus concentration (mass/volume)
M = annual mass inflow of phosphorus (mass/year)
Q = annual volume of water outflow from the lake
Ao = lake surface area
L = M/Ao = areal phosphorus loading (mass/area/year)
q_s = Q/Ao = areal water loading (length/year)
v_s = apparent settling velocity for phosphorus (length/year)

This equation forms the basis of an input-output model first developed by Reckhow (1979) and later modified and automated by Sabol (1987). Using least squares regression, it was found that the apparent settling velocity could be fit as a function of areal water loading. The resulting model, LAKEPHOS, was expressed:

$$P = \frac{L}{11.6 + 1.2q_s} \tag{2}$$

Areal phosphorus loading (L) is calculated by dividing total mass loading of phosphorus (M) by the area of the lake (Ao). Mass loading from the various land use types in the watershed was determined by:

1. Calculating the areal coverage of different land uses in the watershed (see Section 4.2.4),

2. Selecting appropriate phosphorus export coefficients (amount of phosphorus per unit area per year) for each land use type, and

3. Multiplying the area of each land use type by the selected export coefficient and summing the

mass loadings.

Selection of the appropriate land use coefficients is critical to the modeling exercise. An extensive treatment of export coefficients is presented by Reckhow and Simpson (1980). From this document, high, most likely, and low coefficient values were selected. In contrast to a single value based on one export coefficient, the three values result in a range of loading values that is representative of the level of uncertainty inherent to the modeling process. Table 29 lists the land use categories resident in LAKEPHOS and the coefficients selected for Lake of the Woods.

Table 29. Land use categories and phosphorus export coefficients used in the LAKEPHOS model.

Landuse Category	P Export Coefficient (kg/ha/yr) Low	Likely	High
Forest	0.02	0.07	0.14
Row Crop Agriculture	0.75	2.24	5.55
Non-row Crop Agriculture	0.35	0.76	1.81
Pasture	0.16	0.81	3.80
Open/Fallow	0.14	0.19	0.25
Low Density Residential	0.19	0.69	1.10
High Density Residential	0.43	0.92	1.10
Commercial	0.66	1.08	1.70
Institutional/Recreational	0.56	2.37	4.08
Gravel Pits and Landfills	No Values Available		
Water and Wetlands	Assumed "0"		

Total annual phosphorus loading to Lake of the Woods, based on the values shown in Table 29, are shown in Table 30. The range derived for total loading was 3,556.16 pounds (1,612.77 kg) to 22,221.88 pounds (10,077.95 kg). The "most likely" value was 9,327.06 pounds (4,229.96 kg). Additionally, a range of inputs for the runoff and septic components of total phosphorus loading was generated. LAKEPHOS predicts a single "most likely" value for annual phosphorus loading in precipitation. The LAKEPHOS model was also used to predict in-lake phosphorus concentration for Lake of the Woods, based on application of Equation 2, Section 4.2.6. As seen in Table 30, the predicted range of mean water column phosphorus concentrations was 82.59 ug/l to 516.06 ug/l. The predicted "most likely" in-lake phosphorus concentration, based on current land use patterns in the watershed, was 216.60 ug/l. This value is in close agreement with the observed mean water column value of 210 ug/l derived from lake samples collected on 6 September 1990.

As seen in Figure 18, annual phosphorus loading from runoff, i.e., the nine land uses representing watershed inputs, greatly exceeded inputs from septic systems and precipitation. Values for phosphorus loading in runoff ranged from 2,889.01 pounds (1,310.24 kg) to 21,240.92 pounds (9,633.07 kg) with

Table 30. Annual phosphorus inputs and in-lake phosphorus concentration predicted by the LAKEPHOS model.

Phosphorus Mass Loading Source	Loading Estimate (lbs/kg) Low	Likely	High
Runoff (All land uses)	2889.08 /1310.24	8625.56 /3911.82	21240.92 /9633.07
Septic Systems	431.36 /195.63	465.78 /211.24	745.25 /337.98
Precipitation input	235.71 /106.90	235.71 /106.90	235.71 /106.90
Totals	3556.15 /1612.77	9327.05 /4229.96	22221.88 /10077.95
Predicted Lake P Concentration (*ug/l*)	82.59	216.6	516.06

a "most likely" input of 8,625.56 pounds (3,911.82 kg). Phosphorus loading from row crops contributed over 90 percent of the loading from all runoff land uses combined. Predicted septic inputs ranged from 431.36 pounds (195.63 kg) to 745.24 pounds (337.98 kg) with a "most likely" input of 465.78 pounds (211.24 kg). Precipitation contributed 235.71 pounds (106.9 kg) annually.

As previously mentioned, estimates of septic contributions of phosphorus to Lake of the Woods calculated during this study were in close agreement with estimates reported in the 1982 report (Senft and Roberts, 1982). However, as a proportion of total annual phosphorus loading, the 1982 study reported a significantly greater septic contribution (21%) than that determined during this study (5%). According to the 1982 study, total phosphorus loading from all sources amounted to 1,082 kg per year, which was 26% of the "most likely" total calculated during this study (4,229.96 kg). Given the similarity in septic loading values, and examination of the loading coefficients used, it is apparent that the 1982 study underestimated phosphorus loading in runoff. In contrast to the nine land use types that were identified during this study, the 1982 study combined all land uses into three groups; forest, agriculture, and urban. Precipitation, septic contributions, and "miscellaneous" were the other three categories used. The high, most likely, and low phosphorus loading values assigned to the urban land use were all greater than the agricultural values, all of which were much lower than the values used during this study. The relative lack of precision in land use delineation, and the low values assigned to agricultural land use, are the most likely reasons for the large differences observed in runoff phosphorus loading, and the percentage of septic loading of the total annual phosphorus loading.

Confidence in the phosphorus values reported in this study is very high. The LAKEPHOS model used is an automated version of the original Reckhow and Simpson model. It was developed by IS&T Senior Scientist Jeffrey Sabol while he was a graduate student of Dr. Reckhow at Duke University. The areal coverage of the nine land uses identified was determined using digital computer files developed by IS&T from aerial photos of the watershed. Loading values assigned to these land uses were based on a comprehensive evaluation of all values reported in Reckhow and Simpson (1980). Location of reported results, type of tillage and other farming practices, and information on soils and geology were the most

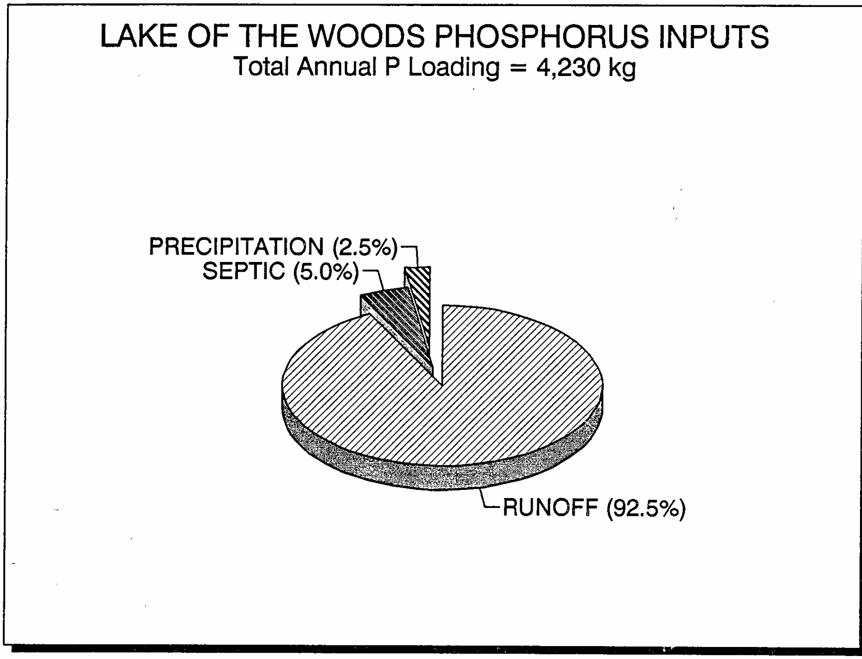

Figure 18. Total annual phosphorus loading to Lake of the Woods.

important criteria used in choosing the values shown in Table 29.

The results of the annual phosphorus modeling can be used to estimate the contribution, i.e., percent of annual phosphorus loading, made by the 2 year, 24 hour storm modeled using AGNPS (2.7 inches of rainfall). The AGNPS model showed a total phosphorus loading to Lake of the Woods of approximately 3,527 pounds (1,600 kg) of phosphorus to the lake. Using the "most likely" annual phosphorus loading predicted by LAKEPHOS, the phosphorus contribution from this single storm event represents 37.7% of total annual phosphorus inputs.

4.2.8 Wetland Identification

The land use map shown in Figure 9 shows only a small amount of acreage identifiable as existing wetlands within the Lake of the Woods watershed (22 acres). However, comparison of these results with the National Wetland Inventory (NWI) Maps for Marshall County indicate that this is an underestimate of wetland acreage for the watershed. A summary map of wetlands identified through the NWI is shown as Figure 19. This map, designed by Robert Rolley of IDNR Division of Fish and Wildlife in Bloomington, IN, was prepared by stereoscopic analysis of high altitude aerial photographs taken during the early 1980's. Due to scale limitations, many small wetlands and linear features, i.e., roads, etc., are not depicted. The map is not intended for and should not be used for regulatory purposes. Based on a comparison of the wetland areas within the watershed boundary to the 416 acre lake, it appears that there are approximately 100 acres of wetlands within the Lake of the Woods watershed. In the County as a whole, the NWI maps show 21,230 acres of wetlands. This figure includes open water areas as well as several different categories of marsh and forested wetlands. Field reconnaissance is always required to confirm areas identified as wetlands on the NWI maps. Methods used to confirm an area as a wetland must conform to guidelines established by the U.S. Army Corps of Engineers and the U.S. EPA. The Marshall County Soil Conservation Service can provide further information on wetland identification in the County.

The NWI maps do not depict areas that were wetlands but are now in a drained or otherwise altered condition. However, identification of soils in the Lake of the Woods watershed showed that over 40 percent are classified as hydric, i.e., a soil that, in an undrained condition, is saturated, flooded, or ponded long enough during the growing season to develop conditions that favor the growth and regeneration of wetland vegetation. In conjunction with vegetation and hydrological requirements, the presence or absence of hydric soils is the determining factor in classifying an area as a wetland. Knowledge of the types and locations of hydric soils within the watershed can therefore be used as reliable indicator of the extent and location of historical (drained) wetlands. The dominant hydric soil in the watershed is Rensselaer loam, with sizable pockets of Houghton muck interspersed throughout. The names and approximate areal coverages of hydric soils within the Lake of the Woods watershed are shown in Table 31. This information, in conjunction with the Marshall County Soil Survey, can be used to identify areas that were likely to have been wetlands prior to being drained for agricultural purposes.

Table 31. Areal coverage of hydric soils within the Lake of the Woods watershed.

Soil Phase	Areal Coverage (acres)
Adrian muck-drained	198
Brookston silt loam	385
Edwards muck	10
Gilford sandy loam	173
Houghton muck-ponded	12
Houghton muck-drained	780
Milford silty clay loam	8
Palms muck-drained	165
Pinhook sandy loam	66
Rensselaer loam	1141
Wallkill silt loam	5
Washtenaw silt loam	5
Total Areal Coverage	2948

Recent research on the benefits of wetlands to water quality and wildlife has led to large scale wetland restoration efforts across the country, particularly in the Midwest. In Indiana, a highly successful program conducted by the U.S. Fish and Wildlife Service (USFWS) and the SCS has resulted in the restoration of thousands of acres of drained wetlands. In addition to this program, farmers may currently enroll privately owned wetlands, streambanks, and highly erodible areas in the Conservation Reserve Program (CRP). Areas enrolled in the CRP are taken out of agricultural production for a period of 10 years and enhanced to reduce erosion. In return, the farmer receives annual rental payments from the U.S. Department of Agriculture (USDA). One option available under the CRP is wetland restoration. The construction of the wetland is financed and contracted by the USFWS. At the end of 10 years, the farmer may renew the agreement, or cancel it and return the area to agriculture. These wetlands, once restored, have been found to provide resting and nesting habitat for numerous waterfowl during the first season following restoration. Erosion reduction and subsequent water quality enhancements are significant benefits derived from wetland restoration. Restoration of drained areas to wetlands may be achieved by inactivating the apparatus responsible for draining water from the soil. Generally, inactivation involves the breakage of tiles or blockage of drainage ditches. Information on restoration of wetlands in Indiana can be obtained from the USFWS following address:

Forest Clark, Biologist
U.S. Fish and Wildlife Service
Ecological Services
Bloomington Field Office
718 North Walnut Street
Bloomington, IN 47401
(812) 334-4261

4.3 SOURCES OF SEDIMENTS AND NUTRIENTS

Based on the results of the watershed analysis, tributary sampling, and visual observations the dominant sources of sediments and nutrients were identified for Lake of the Woods. The following sections outline principal sources of each type of pollutant in the watershed.

4.3.1 Sediments

Whether originating on agricultural fields or in stream channels, sediment yields vary greatly from storm to storm. Within a given area, the largest annual sediment loads in runoff are often 20 times greater than the minimum sediment loads (NCAES, 1982). Even within the same stream, concentrations of suspended solids can vary by a factor of 10 for a given rate of water discharge. Therefore, even though areas have been identified in this study as potential sediment trouble spots, others that were not captured by this investigation may exist.

The AGNPS modeling indicated that sediment inputs are generated by upland sources in the watershed. In general, the areas with the highest erosion rates, as identified by the AGNPS model, are those with intensive-till farming in areas with sloping terrain. The AGNPS cells exhibiting the highest erosion rates had land slopes ranging from 5.3% to 8.5%, and were utilized predominantly for rowcrop agriculture.

It should be emphasized that, despite the results of the AGNPS model, which identified key problem areas with respect to erosion, the results of the bathymetric survey and tributary sampling do not indicate that sedimentation is a major problem in the Lake of the Woods watershed. The sedimentation rate calculated for the lake was moderate, and there was little evidence that sediment transport from the major tributaries was adversely affecting water quality.

4.3.2 Nutrients

The most important plant nutrients impacting the trophic status of lakes are, in general, nitrogen and phosphorus. Based on the N:P ratios in Lake of the Woods (i.e., >21:1), it was concluded that phosphorus was the limiting nutrient. This study determined that of the major external sources of phosphorus to Lake of the Woods, runoff from agricultural areas in the watershed was by far the most important contributor to eutrophication of the lake. Leachate from septic systems was responsible for 5% of phosphorus inputs, while precipitation supplied 2.5%. Internal release of phosphorus from the lake sediments may be significant, but was not quantified during this study. Internal loading most commonly occurs in the Spring and Fall when wind-mediated mixing of phosphorus-rich hypolimnetic (i.e., bottom) waters and surface waters takes place. The phosphorus in hypolimnetic waters is released from sediments during periods of anoxia common during summer and winter. Mixing results in higher surface water concentrations of phosphorus and encourages plant growth in the photic zone.

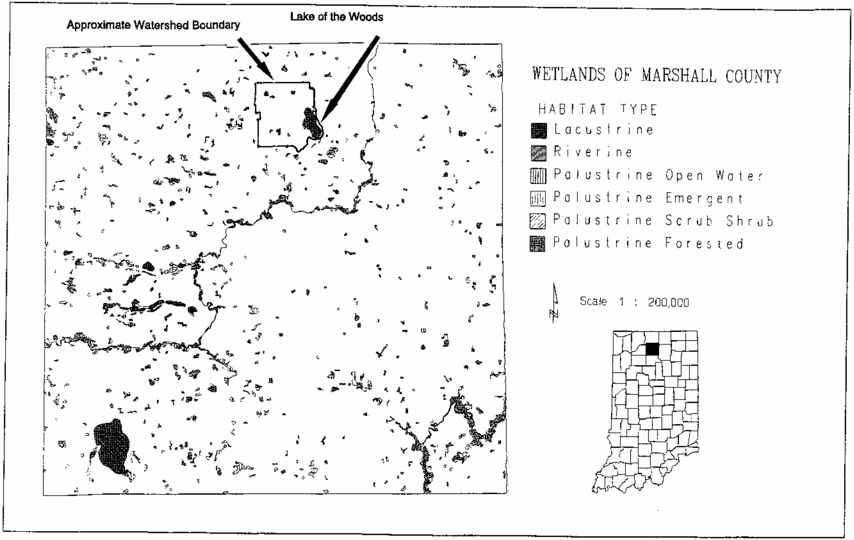

Figure 19. Wetlands of Marshall County showing the Lake of the Woods watershed. **Note: Not to be used for regulatory or legal purposes.**

SECTION 5. SEDIMENT AND NUTRIENT CONTROL IN THE WATERSHED

The following section is a discussion of the types of BMP's (best management practices) designed to that are expected to have the greatest role in reducing nutrient concentrations in Lake of the Woods. Section 5.1 focuses on erosion control techniques that will reduce both nutrient and sediment transport to streams. The techniques described are primarily aimed at reducing loading from agricultural areas, however urban erosion control is also discussed. Section 5.2 provides an overview of best management practices (BMPs) for nutrient reduction specific to agricultural areas. This section also includes recommended maintenance procedures for lawns adjacent to the lake. Section 5.3 discusses applicable in-lake restoration techniques. With respect to in-lake restoration, the cost effectiveness of these methods to improve lake water quality, such as aeration, dredging, or alum treatment, is directly related to the degree of watershed BMP application. For example, if no-till agriculture is practiced on a majority of the watershed, the lifespan of treatments aimed at lake nutrient reduction will be significantly lengthened.

5.1 EROSION CONTROL

This section provides an overview of agricultural BMP's that have been developed for erosion control on cropland, pastures, and streambanks. Within the Lake of the Woods watershed, erosion control is especially important on lands adjacent to or near the major tributaries to the lake (Martin and Walt Kimball Ditches).

Although not classified specifically as lake restoration techniques, erosion control practices maintain productivity on the land, reduce costs of fertilizers and pesticides, and ultimately benefit receiving streams and lakes. The Soil Conservation Service has published design criteria for a variety of BMP's, including those discussed below. This agency has and will continue to provide guidance to individual farmers and land owners in selection and implementation of BMP's. The following summary is drawn from a manual developed by the U.S. EPA, in conjunction with the North American Lake Management Society (NALMS), entitled The Lake and Reservoir Restoration Guidance Manual, published in 1990. Other sources of information include technical publications received through extension services and the SCS.

5.1.1 Agricultural Erosion Control

Conservation Tillage

Erosion in agricultural areas of the watershed can be significantly reduced by conservation tillage practices. The objective of this type of BMP is to protect soil from wind and water erosion by increasing the amount of crop residue. No till farming, where the topsoil is left essentially undisturbed year round, and minimum tillage are forms of this BMP. The effectiveness of these practices in reducing sediment loss and runoff is considered fair to excellent, depending on the degree of tillage reduction (USEPA, 1990). Phosphorus in runoff can be greatly reduced with conservation tillage, however nitrogen concentrations are largely unaffected. In fact, total nitrogen and herbicide concentrations may increase in groundwater as a result of no till practices, a potential negative side effect. Groundwater contamination can be minimized when appropriate management practices and application rates are applied and high residue is maintained. Fertilizer management and integrated pesticide management should accompany conservation tillage practices.

Contour Farming/Stripcropping

Contour plowing and contour stripcropping are effective in reducing soil loss on farm land with a 2-8 percent, and 8-15 percent slope, respectively. Both practices require plowing along the natural contours. In stripcropping, grasses or other close growing crops are planted between row crops, such as corn or soybeans.

Streamside Management/Buffer Strips

Vegetation planted between a stream and plowed field (a buffer strip) is extremely effective in reducing both nutrient and sediment inputs, and in protecting riparian habitat. A study conducted by IS&T for the U.S. EPA showed that buffer strips significantly improve the quality of biological resources (fish and macroinvertebrates) in agricultural areas (IS&T, 1990). This is a very cost effective practice. Once established, a buffer strip will maintain itself indefinitely. Parameters that determine the effectiveness of filter strips include filter width, slope, vegetation type, and application rate of fertilizers. The recently enacted Filter Strip Law (HB 1604) allows filter strips to be classified for property tax purposes and assessed at a rate of $1.00 per acre. Further information on this can be obtained through the Soil and Water Conservation District.

Other Erosion Control Practices

Management of pasture lands to prevent overgrazing, thereby reducing soil compaction and runoff, is important in an overall sedimentation control plan. Stream banks should be fenced to prevent access to cattle and destruction of soft banks. Crop rotation, terracing, and soil stabilization are also effective in reducing sediment inputs to streams.

5.1.2 Urban/Residential Erosion Control

Control of erosion due to development or construction activities must be a component of a watershed-wide approach to reduce future sedimentation in Lake of the Woods. Factors that influence the type and amount of erosion include the nature and extent of vegetative cover, topography; and the frequency, and intensity of rainfall events.

Vegetative cover plays a critical role in controlling erosion by absorbing the impact of falling rain, holding soils together, increasing the retention capacity of soils, and slowing runoff velocity.

Evapotranspiration by plant cover also aids in reducing erosion by removing water from soils between rainfall events.

Topographic characteristics (i.e., slope, size, and shape) of the drainage basin have a strong influence on the amount and rate of runoff. Changes to site topography resulting from development can have a significant impact on the quantity of runoff, and therefore sediment, that is generated.

The characteristics of surface and subsurface soils are fundamental to the resistance of soils to erosive forces, and to the nature of the sediment that results from erosion. Soils with high sand and silt content are normally the most highly erodible. Increasing organic and clay content result in decreased erodibility, however these soils are more easily transported.

In general, the following practices may be applied to control erosion due to land development activities within the Lake of the Woods watershed. These practices are not presented in detail. An excellent source of further information specific to Indiana is the Hoosier Heartland Resource Conservation and Development Council's Urban Development and Planning Guide (HHRCDC, 1985). Another recently developed document is designed to provide Indiana Counties and local governments with a model erosion control ordinance (HERPICC, 1989). This document, entitled "A Model Ordinance for Erosion Control on Sites With Land Disturbing Activities" was developed by a task group composed of engineers, planners, university professors, SCS personnel, and County Commissioners from across the State of Indiana. HERPICC, the Highway Extension and Research Project for Indiana Counties and Cities, is a Purdue University Extension Service that administered the project. Copies of the ordinance may be obtained by writing HERPICC at:

Civil Engineering Building
Purdue University
West Lafayette, IN 47907
(800) 428-7639.

Phased Construction

Phasing construction activities minimizes the extent of land disrupted at one time, reducing the sediment load to a receiving stream or lake during a given storm event. If multiple structures are to be built over an extended period, the entire area slated for development may not have to be cleared at once.

Road Stabilization

Several practices are available to minimize erosion and sediment transport due to traffic in construction areas. These include stabilization of freshly graded road surfaces with gravel and installation of gravel pads at entrances to construction sites. The latter serve to reduce the amount of sediment carried off-site on tires of construction vehicles.

Sediment Barriers

Various types of barriers may be placed in the path of runoff to detain sediment and decrease flow velocities. These barriers, consisting of hay or geotextile filter fabric, are placed across or at the toe of slopes. Sediment barriers are also effective in protecting storm drain inlets from construction site runoff.

Sediment Traps and Basins

Temporary basins may be constructed to contain flows long enough for sediment to settle out. These basins are characteristically simple, often consisting of a small pond formed by an earthen dike, with a gravel lined outlet.

Establishment of Vegetative Cover

Planting of fast growing grasses and other plants provides a means for quickly stabilizing disturbed areas. The choice of plant type will depend on the intended permanency of the cover. Mulching with straw and other fibrous materials will aid in establishment of protective vegetation. This in itself will reduce erosion and runoff on disturbed areas.

For future developments in the watershed, an erosion and sediment control plan should be developed to address the potential problems resulting from the particular activity. The plan should clearly present the anticipated erosion and sedimentation problems that are likely to result, and the measures that will be taken to mitigate them. Both narrative and graphical sections should be included. The narrative section should include the following:

- Brief description of the project
- Existing conditions (physical features, slope, etc.)
- Description of adjacent areas that may be impacted
- Summary of soil characteristics
- Identification of problem areas (high slope, erodible soils, etc.)
- Erosion and sediment control measures to be used
- Description of post construction stabilization and practices, including measures to control storm water runoff
- Storm water runoff concerns and impacts
- Inspection and maintenance schedules planned
- Calculations used in design of basins, waterways, and other structural controls.

Graphical materials in the site plan should provide the necessary maps and related materials, including:

- Vicinity map showing site location
- Current elevation contours

- Existing vegetation types and locations
- Soils
- Critical erosion areas
- Existing drainage patterns
- Proposed contours after grading
- Limits of clearing and grading
- Location of erosion and sediment control practices
- Detailed drawings of structural practices to be used

The final plan should be subject to approval of a county or local planning board or similar group, and should provide comprehensive documentation of the erosion and sediment control strategies to be applied in the development of the site.

5.1.3 Costs of Erosion Control Measures

The costs of implementing previously described BMPs are an obvious concern to many landowners wishing to contribute to conservation efforts in the watershed. However, in most cases, some type of cost share assistance is provided through Soil and Water Conservation District, Soil Conservation Service, or other State programs such as the IDNR Lake/Watershed Land Treatment Program. Cost share assistance of up to 80% is available through the latter program. In addition to costs, the relative effectiveness of the BMP in reducing sediment, nutrients, or runoff is an important consideration. The commitment to expend financial resources should be made with knowledge that the particular BMP will be the most effective for the money, and is the best suited method given the physical constraints of the area and the particular farming operation. SWCD District Conservationists will be the best resource in assisting in this process. Cost estimates of commonly applied BMPs are shown in Table 32. Designed primarily as sediment control measures, the majority of these BMPs also are effective in reducing nutrient concentration in runoff, and runoff quantities. The relative effectiveness of many of these BMPs in reducing sediment loss (erosion), nutrient concentrations, runoff, and the overall confidence in the method is shown in Table 33. This information was compiled from an extensive survey of literature on BMP effectiveness.

5.2 WATERSHED NUTRIENT REDUCTION

In addition to causing nuisance algae and other water quality problems in the lake, excessive nutrient loading can result in groundwater contamination and human health effects. Erosion control measures will decrease sediment bound nutrient loading, however a reduction in the transfer of soluble fractions of phosphorus, and particularly nitrogen must also be a management priority. Animal wastes and fertilizers are two key sources of soluble nutrients in the watershed. The section below focuses on BMP's designed specifically to reduce soluble inputs. Animal wastes from feedlots and confinement areas, application of animal manures as fertilizers, and commercial fertilizers themselves are primary sources of soluble nitrogen and phosphorus. BMP's for pasture management and stream protection are also described. As

Table 32. **Cost estimates for selected erosion/sediment control strategies.**[1]

Conservation Practice	Areal Units	Flat Rate Install. Costs $	Life-span Yrs.	Annual O&M % Costs	Annual Total Costs $
Conservation Planting					
Contour	Acre	10.00	10	5.00	2.23
Field	Acre	5.00	10	5.00	1.12
Wind-10 rod strips	Acre	4.00	10	5.00	0.89
11-20 rod strips		3.00	10	5.00	0.45
21-30 rod strips		2.00	10	5.00	0.45
Contour Farming	Acre	3.00	Annual	None	3.35
Critical Area Planting					
Shaping	Acre	200.00	25	3.00	30.62
Seed, Seeding Fertilizer, lime	Acre	220.00	25	3.00	33.68
Mulching (straw) (Anchored by treading)	Acre	425.00	1	0.00	473.88
Sodding	Sq. Yard	2.50	5	3.00	0.38
Pasture and Hayland Cover					
Tame species seeded with companion crop	Acre	130.00	15	3.00	22.48
Tame species with seedbed preparation	Acre	140.00	15	5.00	27.01
Native species with seedbed preparation	Acre	100.00	15	5.00	19.29
Interseeding with legume	Acre	85.00	6	5.00	24.63
Diversion (includes seeding/ mulching)	L. Feet	2.50	10	5.00	0.56
Grassed Waterway or Outlet (Includes seeding/mulching)	Acre	2000.00	10	3.00	406.75

[1]SCS estimates for state of Indiana (including interest payments @ 11.5%). All dollar amounts are subject to change based upon local conditions, material costs, and labor costs.

Table 32. Cost estimates for selected erosion/sediment control strategies[1] (Concluded).

Conservation Practice	Areal Units	Flat Rate Install. Costs $	Life-span Yrs.	Annual O&M % Costs	Annual Total Costs $
Grasses and Legumes in Rotation	Acre	Considered as a production cost for crops.			
Sediment Basin	Cu Yard	1.25	25	5.00	0.22
Water & Sediment Control Basin	Cu Yard	2.00	15	5.00	0.39
Grade Stabilization Structure (4' Overfall)					
Rock Chute	Job Est.	1,500.00	25	3.00	229.65
Aluminum:					
<170 CFS	Job Est.	3,200.00	25	3.00	489.91
>170 CFS	Job Est.	4,800.00	25	3.00	734.87
Concrete Block Toewall	Job Est.	2,500.00	15	3.00	432.31
Reinforced Concrete	Job Est.	3,250.00	40	3.00	476.12
Wood	Job Est.	2,250.00	20	3.00	359.34
Concrete Block Chute	Job Est.	1,800.00	25	3.00	275.58
Grade Stabilization Structure (6' Overfall)					
Aluminum	Job Est.	8,000.00	25	3.00	1224.78
Wood	Job Est.	5,000.00	20	3.00	798.52
Reinforced Concrete	Job Est.	9,000.00	40	3.00	1318.48
Rock Chute	Job Est.	2,500.00	25	3.00	382.74
Concrete Block Chute	Job Est.	3,000.00	20	3.00	479.11
Mulching (Anchored by)					
Treading	Acre	300.00	2	None	8.19
Netting	Sq Yard	0.30	5	None	0.08
Asphalt Emulsion	Acre	400.00	5	None	109.59
Mulch Blankets	Sq Yard	1.00	2	1.00	0.60
Pasture and Hayland Management					
Pasture Continuous grazing	Acre	18.00	Annual	None	20.07
Rotation grazing	Acre	33.00	Annual	None	36.80
Terrace					
Gradient	L. Feet	1.50	20	2.00	0.22
Broadbased Parallel	L. Feet	2.75	15	2.00	0.45
Narrow Parallel	L. Feet	1.50	15	2.00	0.24
Grassed Back Slope	L. Feet	2.00	20	2.00	0.30
Riser Inlets	Each	50.00	20	5.00	8.99
Field Border/Filter Strips (1 rod wide)	1/2 mi	150.00	10	5.00	33.51

[1]SCS estimates for state of Indiana. All dollar amounts are subject to change based upon local conditions, material costs, and labor costs.

Table 33. Efficiency and confidence of selected agricultural best management practices.

Best Management Practice	Removal Efficiency					
	Sediment	**N**	**P**	**Runoff**	**Pesticides**	**Confidence**
Conservation Tillage	60-98%	P	40-95%	25-61%	80-90%	G
Cover Crops	to 95%	G	NA	G	F	G
Critical Area Planting	G	U	U	G	U	G
Diversion	30-60%	30-60%	30-60%	P	NA	P-G
Filter Strips	to 79%	67-84%	to 67%	to 67%	NA	G
Terraces	50-98%	U	U	42-73%	NA	G-E
Grassed Waterway	60-80%	U	5-40%	F-G	5-40%	G
Animal Waste Mgmt.	NA	G-E	80-90%	NA	NA	G
Pasture/Hayland Mgmt.	G	U	U	G	NA	G-E
Pest Mgmt.	NA	NA	NA	NA	20-40%	G
Streambank Protection	G	P	P	F	NA	P
Wetland Construction	to 92%	68-88%	37-92%	G-E	U	G

E=Excellent H=High P=Poor
F=Fair L=Low U=Unknown
G=Good NA=Not Applicable

is the case for BMPs designed for sediment control, cost share assistance is possible for the majority of these practices.

5.2.1 Animal Production and Keeping

The need for confinement of animals in feed lots or holding facilities, as opposed to open pastures, results in highly concentrated runoff. Summaries of several BMP's that have been designed to address problems associated with confinement areas on the following pages.

Roofing

On the average, the Lake of the Woods watershed receives over three feet of rainfall per year. This means that for each acre of open confinement area, close to a million gallons of contaminated water are generated on an annual basis. Washdown water may equal this amount. Roofing confinement areas allows separation of clean runoff from contaminated slab runoff. Roof gutters and a water collection system greatly reduce the amount of water that must be treated.

Location

The amount of pollutants entering a stream decreases with distance from the source. The distance where zero pollution enters a waterway has been estimated to be 98 to 393 feet, depending on soil characteristics, grass type, and density of cover (Novotny and Chesters, 1981). Confinement areas should be built up and graded away from a ditch or stream. Animals should be fenced no closer than the top of the grade. The ditch slope should have a grass cover, and the runoff from the storage facility should be retained.

Washdown Water

BMP's for the use of washdown water focus on recycling and reduction in the quantity of water used. Substituting higher water pressure for volume and scraping manure prior to hosing minimizes water usage.

Manure Storage Lagoons

Farms with a limited capacity for liquid manure storage must frequently spread the lagoon contents on pasture land to prevent overflow. This often results in ponding of the liquid waste during periods when the ground is saturated, e.g., following snowmelt in the spring. Manure applied under these conditions is likely to flow off of the field and into a waterway. Installation of a solids separator ahead of the lagoon increases the capacity of the lagoon and lengthens the period between cleaning. In addition, odor problems are reduced.

5.2.2 Manure Application to Pastures

Although no data are available for the Lake of the Woods watershed, it is probable that a large percentage of manure that is produced from animal production is returned to the land. There is general agreement that manure can and should be used in crop production to increase yields and fertility. However, water quality degradation will occur without proper management of manure application. Proper timing of application (i.e., during non-saturated conditions), application to land with minimal slope, addition of manure in quantities equal to crop requirements, and avoidance of soil compaction during the application process will minimize problems due to manure application.

5.2.3 Fertilizer Management

Application of fertilizers in quantities equal to crop needs will greatly reduce nutrient enrichment of aquatic resources due to agricultural operations. Reducing the loss of nutrients to the groundwater or air is dependent on proper soil testing, and establishment of realistic yield goals. Knowledge of the contribution that legumes, manure, and crop rotation make to soil nitrogen and phosphorus levels is critical to determining proper application rates.

Nitrogen

Over-application of nitrogen has been recognized as a significant problem in agricultural areas throughout the country. The nitrogen concentration in the Lake of the Woods sediment samples was high, and suggests over-application of nitrogen to croplands in the watershed. Although some degree of over-application is necessary given significantly less than 100% uptake efficiencies, current research on this problem points to a lack of consideration of alternative sources of nitrogen, such as manure or alfalfa, in calculating the quantity of fertilizer necessary for a given yield (Granatstein, 1988). Nitrate in soils in excess of crop requirements results in groundwater contamination, as well as increasing eutrophication of surface waters. Nitrogen "credits", i.e., a reduction in the amount of nitrogen necessary due to carryover from previous crops (legumes) or to crop rotation result in both cost benefits to farmers and improved water quality. Examples of nitrogen credits, in terms of pounds/acre N for previous legume crops, are shown in Table 34. This information is taken from material published in a University of Wisconsin Extension Bulletin (Granatstein, 1988). The Marshall County SWCD District Conservationist, Jerry Pearson, can provide additional information on nitrogen management.

Phosphorus

Phosphorus is not as mobile a nutrient as nitrogen, and will tend to remain in the soil for longer periods of time. Erosion will reduce soil phosphorus levels, however in many cases, phosphorus levels will have built up over the years, and continued, or "maintenance applications", may not be economically justified (Granatstein, 1988). As with nitrogen, the rate of application of commercial phosphorus fertilizers can be reduced or even eliminated when fertility credits from manure are accounted for. A program of

Table 34. Nitrogen credits for previous legume crops (from Granatstein, 1988).

CROP	NITROGEN CREDIT
Forages	
Alfalfa	40 lb. N/ac. plus 1 lb. N/ac. for each percent legume in stand.
Red Clover	Use 80% of alfalfa credit.
Soybeans	1 lb. N/ac. for each bu/ac. of beans harvested up to a maximum credit of 40 lb. N/ac.
Green Manure Crops	
Sweet Clover	80-120 lb. N/ac.
Alfalfa	6-100 lb. N/ac.
Red Clover	50-80 lb. N/ac.
Vegetable Crops	
Peas, snapbeans, limabeans	10-20 lb. N/ac.

regular soil testing combined with maintenance of proper soil pH is essential to avoid over application of phosphorus.

Timing of application is also a key factor in reducing the quantity of fertilizers that reach ground or surface waters. In general, application in the fall results in significant runoff and loss during the non-growing season. Spring pre-plant application is recommended.

5.2.4 Septic Systems

Septic systems within the watershed, and more importantly, on the lakeshore, are a source of nutrients. The results of an analysis of septic contributions from lakeshore residences during this Feasibility Study indicated that five percent of the phosphorus entering the lake from external sources is from lakeshore septic systems. While this is a far lower percentage than the runoff contribution, improved maintenance and proper placement can greatly reduce these inputs. The following paragraphs offer general guidance on installation, use, and maintenance of septic systems.

Proper Location

The features governing appropriate placement of septic systems include proper soils and adequate buffer distances between the drain field and sensitive areas. Information is available from both the SCS and USGS concerning the suitability of various soils and geologies for drain field construction. These agencies should be consulted prior to installing any new system. The Indiana State Board of Health should also be contacted to determine the most recent limitations concerning minimum distance of the drain field from drinking supplies, lakes, drainage ditches, etc.

Regular Inspection and Maintenance

A septic tank should be inspected at least once per year to assess the rate of solids accumulation. If these materials build up, they will be transferred with the waste to the drain field, resulting in clogged soil pores. This condition results in a reduction of permeability, and eventually construction of a new drain field. Septic system maintenance should involve inspection of "Tee-joints" and distribution boxes, since these parts are especially prone to shifting that can lead to uneven dispersal of waste water into the drain field. Material removed from the tank should be discharged at a treatment plant. Periodic inspection and pumping will avoid this expense.

Drain Field Protection

Trees should not be allowed to grow on top of the drain field. Tree roots can penetrate the field, diminishing its efficiency. Vehicular traffic should also be prevented, since this will cause compaction of the leach field soils.

Proper Use

Solids, greases, or toxic materials should not be disposed of in septic systems. Solids, such as paper towels and disposable diapers, add to the overall load of the system, decreasing efficiency and increasing maintenance costs. Fats, oils, and greases can solidify in the system and create blockages. Toxic materials (e.g., paints, motor oil, pesticides) are not decomposed by septic systems and can leach out into groundwater, contaminating wells and eventually reaching lakes and streams. In addition, these materials can kill the beneficial bacteria responsible for decomposing normal septic system wastes.

Additives

Authorities agree that under most circumstances, chemical and biological additives are not needed to accelerate decomposition in the septic field. Under extreme use situations however, these additives may be helpful. Caution must be observed when using these products since some additives will actually inhibit decomposition. Products containing more than one percent of the following chemicals should not be used:

- **Halogenated hydrocarbons:** trichloroethane, trichloroethylene, methylene chloride, halogenated benzenes, carbon tetrachloride;
- **Aromatic hydrocarbons:** benzene, toluene, naphthalene;
- **Phenol derivatives:** trichlorophenol, pentachlorophenol, acrolein, acrylonitrile, benzidine.

A good reference with information on septic system design and maintenance is found in Perkins (1989).

5.2.5 Park and Lawn Maintenance

The following paragraphs provide a summary of maintenance procedures to reduce nutrient inputs to Lake of the Woods from surrounding lawns and park area. The following "common sense" procedures will minimize nutrient concentration in runoff from these areas.

Grass and Leaves

Grass clippings should be allowed to remain on the lawn following mowing unless excessive thatch build-up occurs. This will reduce the need for artificial nutrients. In addition, this will have a beneficial effect on the nationwide waste disposal problem, as bagged grass or leaves comprise 15-20% of all substances placed in landfills (Hugo, 1990). Raked leaves should not be disposed in or near the lake or its tributaries. Instead, they should be bagged and transported to a compost area away from any water flow path. If a compost area is used, runoff should not be allowed to reach the lake or tributaries.

Trash Receptacles

The number of trash cans and dumpsters should be sufficient to handle all trash deposited between collections. The containers should be cleaned with plain water directed from a spray nozzle. Disinfectants should be used sparingly and not allowed to drain onto the ground. Rinse water containing disinfectant must be properly disposed of.

Holes should not be drilled in the bottom of trash barrels to afford better drainage. Water percolating through these containers is high in nutrient and bacterial content, and should be avoided. Trash cans should be covered and not left open. Spring-loaded lids are recommended, and open topped drums should be avoided. Rusty receptacles should be replaced promptly. Trash cans should be placed as far as possible from the lake.

Fertilizers and Chemicals

Application of fertilizers should be avoided or minimized. These products will enhance the growth of algae and macrophytes in the lake if they are present in runoff. Application of other chemicals, such as pesticides and herbicides, should be carefully controlled and avoided if possible. Alternatives to chemical treatment should be investigated.

Automobile Traffic

The exhaust from internal combustion engines is high in metal, hydrocarbon, and nutrient content. So called "tailpipe drippings" are a major source of nutrients in urban watersheds. Drains and waterways along roads and parking lots should be situated so as not to channel runoff directly into the lake or its tributaries. Ideally, stormwater runoff should be routed to a treatment facility (or holding pond). If this is not feasible, runoff should be routed across large, vegetated areas prior to being allowed to enter the lake or its tributaries.

Education Centers

Recreational users of Lake of the Woods should be educated on issues surrounding the lake and its care. Broad-based nature exhibits or storyboards on specific problems, such as why fisherman should not clean their catch in or near the lake (entrails can lead to elevated bacteria counts and reduction in dissolved oxygen) would promote understanding of water quality issues. These types of exhibits could be placed at the public access sites to the lake.

5.3 IN-LAKE RESTORATION

For the long-term health of Lake of the Woods, implementation of the BMP's previously described will be the most effective management strategy. However, in-lake techniques result in immediate improvements in water quality, and represent an interim solution that would enhance the effectiveness of upland BMPs. Although there is a wide range of potential and effective lake restoration techniques (Cook et al., 1986), those aimed at in-lake nutrient reduction (phosphorus control) are expected to have the greatest probability of improving water quality in the lake, given the results of the watershed modeling and chemical analyses. Of the many lake restoration methods designed to address this problem, the techniques discussed below are expected to have the greatest probability of success in restoring water quality and improving the trophic state of the lake.

5.3.1 Phosphorus Precipitation/Inactivation

The terms phosphorus precipitation or inactivation refer to the removal of phosphorus from the water column (precipitation) or the reduction of phosphorus release from the lake sediments (inactivation). These two in-lake restoration techniques both involve the use of aluminum sulfate (alum) to chemically bind and remove phosphorus. The two techniques differ only in the dose applied. In phosphorus precipitation, the aluminum sulfate is added in a quantity sufficient to remove only the phosphorus present in the water column. The alum quickly becomes aluminum hydroxide, which adsorbs and essentially sweeps the water clean of phosphorus. If the alum is added in a sufficiently large dose, inactivation of phosphorus in the sediments of the lake occurs in addition to phosphorus precipitation. The aluminum hydroxide that settles on the bottom of the lake forms a barrier that greatly reduces the transport of phosphorus to the overlying water. This level of treatment has been shown to be highly effective in reducing the water column phosphorus concentration for long periods of time, reducing the phosphorus content of groundwater seeping into the lake, and in bringing about a measurable and lasting improvement in trophic state.

As pointed out in the majority of the literature available on this treatment method, alum treatment should not be conducted unless it is preceded by efforts to reduce phosphorus inputs from the watershed. Efforts from farmers and lakeshore residents in the Lake of the Woods watershed have already demonstrated that erosion control and water quality improvement is a concerted goal. No-till farming is increasingly being practiced in Marshall County, and a sewer system is in the planning stages that would eliminate phosphorus inputs from lakeshore residences. In the long-term, i.e., 5-10 years, lake water quality is expected to greatly improve as a result of these practices. In the interim, alum treatment represents an effective solution to nutrient related problems currently effecting Lake of the Woods. Estimates in the literature of the period of effectiveness for this treatment, assuming that the dose is sufficient to neutralize the sediments, range from five to 10 years for a single application.

The negative effects of an alum application relate chiefly to the potential toxicity of dissolved aluminum, which is toxic to fish. However, this problem only occurs if the alkalinity in the lake is insufficient to buffer the effects of the alum, which is acidic due to the sulfate ion. Low initial alkalinity that is further reduced by the alum can result in a drop in pH. Dissolved aluminum is present (and therefore toxic) below a pH of 6.0, and becomes the dominant form of aluminum at a pH 5.5 to 5.0. At a pH greater than this (pH 6 to 8) studies have shown that deleterious effects of alum treatment are minimal and short-lived. Documented adverse effects of the treatment include a reduction in species diversity of plankton in treated lakes, and, in laboratory tests, mortality of Chironomid insect larvae. The reduction in species diversity occurred in West Twin Lake, Ohio, and was attributed to the physical effects of the floc that settled on the lake bottom, the change in species diversity from blue-green to green algae, and the increased clarity of the water which may have increased predation on zooplankton by fish (Cook et al., 1986). The laboratory tests that showed mortality of Chironomidae were chronic tests, i.e., conducted over a long period of time. These tests showed that a typically applied dose of alum can cause mortality in a common lake insect larvae in a laboratory situation. The researchers pointed out that in-lake conditions might mitigate the observed effects. Another study of four alum treated lakes in Wisconsin showed no damage to invertebrate populations during several years of monitoring (Cook et al., 1986).

The increased clarity of the water following alum treatment often results in increased plant growth, another potential negative factor. However, this is usually a manageable problem, and may act to improve fish habitat in lakes where frequent algal blooms have kept macrophyte growth to a minimum.

The most common recommendation to managers regarding application of alum is to closely monitor pH during the treatment process, and to cease the treatment if the pH falls below 6.0. For Lake of the Woods, it is anticipated that the alkalinity would be more than sufficient to maintain a pH greater than 6.0 during and following an alum application. Alkalinities reported in the 1982 study ranged from 140 to 165 mg/L $CaCO_3$. However, for proper dose determination, alkalinities in each major strata of the lake, e.g., the 15 to 20 foot contour interval, should be determined prior to the application. In practice, the lake is divided in into several zones, based on depth, and the dose corresponding to the alkalinity of the particular zone is then applied.

The simplest method of alum application is to apply a dry form over the back of a moving boat. However, a slurried form has major advantages, the greatest being more rapid dissolution. This form of alum requires either an on-board pump to slurry the dry alum with lake water, or a specially made barge designed to load and apply liquid alum directly. The later is the most efficient method of treatment.

The success of an alum treatment is defined by decreased algal standing crop (commonly measured by Chla) and a decreased phosphorus concentration following treatment. A monitoring program during and immediately following the application is essential to gage the response of the lake and to provide the data necessary to interpret the changes in water quality (see Section 6).

Costs of alum application are largely dependent on labor costs and method of application. The cost of the alum itself (in dry form) is $152 per ton, based on information from General Chemical Corporation in Parsippany, NJ. General Chemical specializes in alum production and application, and their cost was well over $100 per ton less than an Indianapolis based chemical company. Assuming a barge-based operation, the alum would be shipped in slurried form via tanker truck. Discussion in Cook et al. (1986) on dose determination indicates approximately 898 tons of alum would be required, based on a volume to be treated of approximately 2,968 acre feet (lake depth of 10 feet to 45 feet), and an initial alkalinity of 150 mg/L $CaCO_3$. The 1982 Feasibility Study reported alkalinities in the range of 140-165 mg/L $CaCO_3$. This amounts to approximately $136,496.

Further discussion of costs and dose determination with Sweetwater Consultants, a Pennsylvania based firm specializing in alum application, indicates that for lakes with alkalinities in the range of 150 mg/L $CaCO_3$, a quantity of 500 gallons of slurried aluminum sulfate should be applied per surface acre of the lake to be treated. Based on the 1990 bathymetric survey, the treated area would be 240 acres, which includes all area from 10 to 45 feet in depth. This would result in a total of 120,000 gallons of slurried alum. Sweetwater's estimate of the application costs, including the cost of the alum itself ranges from $0.80 to $1.00 per gallon, for a total cost of $96,000 to $120,000. According to Sweetwater consultants, this is a more likely estimate than the volume-based cost mentioned above.

It should be noted that the above cost and dose estimates are based on surface alkalinities reported in the 1982 Diagnostic Feasibility Study. However, discussion with General Chemical Corporation indicates that this information, in addition to the in-situ profile data contained in this report, is sufficient to determine an actual dose for the lake. IS&T would still recommend that a profile (e.g., surface to bottom at five foot increments) of samples for alkalinity measurement be collected prior to application.

For further information on firms experienced in alum application, and general information on the subject, The Lake of the Woods Homeowners Association should contact the North American Lake Management Society (NALMS). This organization is a nationwide non-profit group dedicated to effective lake management, and can be reached at the following address:

NALMS
c/o University of Florida
Research and Technology Park
One Progress Blvd., Box 27
Alachua, FL 32615
(904) 462-2554

In addition to actual application, the chosen firm would be responsible for proper dose determination, the arrangements for transport of the material to the lake, and monitoring of water quality during the treatment process. The EPA Lake and Reservoir Restoration Guidance Manual (1990), Monitoring Lake and Reservoir Restoration (1990), and Cook et al. (1986), are excellent sources of information on alum treatment. The latter reference is the most thorough source, and includes detailed information on dose determination.

In terms of permit requirements for alum application, discussion with the U.S. Army Corps of Engineers indicates that no permit is required for this treatment. However, discussion with John Winters of IDEM indicates that close coordination with IDEM will be required prior to an alum application. The concern of IDEM is that the alum dose be properly arrived at, that the material chosen be of the required composition, and that the overall plan for the application receives their complete review.

5.3.2 Aquatic Plant Harvesting

The objective of aquatic plant harvesting is to cut and remove nuisance growths of rooted aquatic plants and associated filamentous algae. A significant "weed problem" does not currently exist in Lake of the Woods, however the need to remove aquatic plants occurs from time to time in most lakes. In addition, as mentioned above, plant growth may increase dramatically if the lake receives an alum treatment, resulting in the need for more frequent removal, or harvesting, of aquatic plants.

The most common means of harvesting is accomplished through the use of a mechanical weed harvester; a maneuverable, low-draft barge designed with one horizontal and two vertical cutter bars, a conveyor to remove cut plants to a holding area on the machine, and another conveyor to rapidly unload plants. Harvesters vary in size and storage capacity, with cutting rates ranging from about 0.2 to 0.6 acres per hour depending on the size of the machine. Disposal of the cut materials is usually not a problem. Because aquatic plants are more than 90 percent water, their dry bulk is comparatively small. Additionally, farmers and lakeshore residents will often use the cut weeds as mulch and fertilizer.

A reduction in internal nutrient loading is an indirect benefit of aquatic plant harvesting. The direct benefits relate primarily to increased recreational use of the lake. However, nutrient removal and protection of the pelagic zone from nutrients released during macrophyte decay may also result from harvesting. If nutrient income is low to moderate and weed density is high, as much as 50 percent of the net annual phosphorus loading could be removed through intensive harvesting (USEPA, 1990).

Mechanical harvesting, however, is energy and labor intensive. Additionally, plants may fragment and spread the infestation. It is recommended that floating barrier systems be utilized during harvesting to curtail the spread of buoyant plant fragments, and aid in their collection.

Most harvesting operations are effective at producing a temporary relief from nuisance plants, and in removing organic matter and nutrients. In some cases, however, plant regrowth can be very rapid (days or weeks). Conyers and Cooke (1983) and Cooke and Carlson (1986) found that a slower method of lowering the cutter blade approximately one inch into the soft sediments would produce a season-long control of milfoil by tearing out the plant roots (USEPA, 1990). This harvesting method is only effective when sediments are soft and the length of the cutter bar (usually 5 - 6 ft.) can reach into the mud.

Contracted harvesting costs in the Midwest range from $135 to $300 per acre (1987 dollars). Costs for a particular project relate directly to machine cost, labor, fuel, insurance, disposal charges, and the amount of machinery downtime (USEPA, 1990).

SECTION 6. U.S. EPA CLEAN LAKES PHASE II MONITORING PLAN

The following information provides the necessary guidance for both design and implementation of a U.S. EPA Phase II monitoring program for Lake of the Woods. U.S. EPA Clean Lakes Program regulations require that Clean Lakes projects be monitored both during and after implementation of lake restoration. For the purposes of this monitoring program, lake restoration includes the installation of best management practices (BMPs) in the watershed, as well as in-lake techniques. The first portion of this section is aimed at monitoring of watershed improvements. The second portion will be applicable to monitoring that will be required if Lake of the Woods Homeowners Association elects to treat the lake with alum, as discussed in Section 5.3.1.

The objective of a monitoring plan conducted during Phase II implementation is to provide sufficient data to allow the State and the EPA project officer to determine that the desired objectives are being achieved. If the objectives are not being achieved, the project officer would then redirect the project. The EPA regulations also require monitoring of Phase II implementation projects for at least one year after restoration of the lake, or installation of pollution control devices (i.e., best management practices). The purposes of this post-treatment monitoring are to provide the data needed to evaluate the effectiveness of the restoration measures, and to determine if the project objectives were achieved. More detailed information regarding Clean Lakes Program Phase II monitoring requirements can be found in the U.S. EPA publication Monitoring Lake and Reservoir Restoration (Wedepohl, et al., 1990). This publication served as the guidelines for developing the monitoring plan for Lake of the Woods.

The monitoring program design includes sample station locations and sampling frequencies. The parameters to be measured will be described for both monitoring designs (BMPs and alum treatment). Analytical methodologies, quality control/quality assurance requirements, and estimates of laboratory costs are also included.

6.1 SAMPLE STATION LOCATION

The three (3) sampling stations to be monitored in Lake of the Woods and its watershed are listed in Table 35.

Table 35. Lake of the Woods monitoring program sample station identification.

STATION NUMBER	DESCRIPTION
1	Deepest part of Lake of the Woods
2	Walt Kimble Ditch
3	Martin Ditch

One (1) station is located in the deepest part of the lake (based on the 1990 bathymetric survey), one (1) is located on Walt Kimble Ditch upstream of the lake, and one (1) is located on Martin Ditch upstream of the lake.

6.2 SAMPLING FREQUENCY

Lake and watershed sampling will be conducted twice per month from April through September, and once per month from October through March. The watershed sampling frequency should provide a minimum of 13 to 28 samples per year per tributary sampled. To allow for variability, it is recommended that an exact sampling date not be specified, but that the sampling date within each time period be chosen randomly within that time frame. Additionally, because separate storm event sampling is not a component of this monitoring program, it is suggested that the sampling be conducted with no concern for weather such that some rain events will be captured.

Exceptions to this sampling routine will occur only during the recommended alum application to Lake of the Woods. During this application, the sampling frequency will be adjusted for the one in-lake station only. Section 6.7 describes this specific sampling frequency.

6.3 REQUIRED EQUIPMENT

The following equipment will be required to conduct the field sampling:

- Boat with appropriate safety equipment (in-lake station only)
- Dissolved oxygen meter with temperature capability
- pH meter
- Water sample collection bottle (Horizontal Van Dorn or Kemmerer)
- Glass fiber filters, membrane filters and filtration apparatus
- Secchi disk
- Tape measure or yardstick
- Spring-type clothes pins
- Appropriate sample containers and labels
- Deionized water
- In-situ and water sample collection data forms
- Field record book
- Pencils
- Waterproof markers
- Cooler.

6.4 INSTRUMENT CALIBRATION AND MAINTENANCE

Calibrate the dissolved oxygen (DO) and pH meters at the beginning of each sampling day following the manufacturers' instructions. The pH meter should be calibrated using the pH 7 and pH 10 buffers. The calibration date, time and results are to be recorded in a permanent Field Record Book.

Any maintenance performed on either DO or pH meter should be recorded, with the date of maintenance noted, in a permanent Instrument Maintenance Record. Instrument maintenance includes battery replacement as well as changing the dissolved oxygen meter electrolyte and membrane.

6.5 METHODS FOR IN-LAKE MONITORING

The water samples collected must be representative of the lake being described. Therefore, they must be carefully collected, properly preserved, and analyzed using approved methodologies. Listed below are the methods to be used for the routine monitoring of Lake of the Woods.

6.5.1 Parameters

The parameters to be monitored at the one in-lake station are:

- Temperature
- Dissolved oxygen
- pH
- Secchi transparency
- Chlorophyll a
- Total suspended solids
- Total phosphorus
- Dissolved reactive phosphorus
- Nitrite+Nitrate nitrogen
- Ammonia nitrogen
- Total Kjeldahl nitrogen.

Water samples collected from the in-lake station (#1) are to be analyzed for the parameters listed in Table 36. The analytical methods to be used should provide detection limits as specified in the table and be equivalent to the methods listed. The nitrogen series (ammonia nitrogen, total Kjeldahl nitrogen, and nitrite + nitrate nitrogen) will be analyzed only during the months of April, May, and June.

6.5.2 Sampling Procedures

The following steps are to be followed at the one in-lake station (#1) for every sampling event. The in-situ measurements are to be entered on the In-situ Data Form (Figure 20) for the in-lake samples.

1. Anchor the boat upwind of the station marker, allowing the boat to drift down to the station location. This is done to minimize disturbance of the water column and lake sediments by

Table 36. Water quality parameters and analytical requirements for lake samples.

Parameter	Detection Limit	Method No. EPA	SM[1]
Total Phosphorus	0.010 mg/L	365.1	424F
Dissolved Reactive Phosphorus	0.010 mg/L	365.1	424F
Ammonia Nitrogen	0.020 mg/L	350.3	
Nitrite+Nitrate Nitrogen	0.050 mg/L	353.3	
Total Kjeldahl Nitrogen	0.050 mg/L	351.2	420B
Total Suspended Solids	1.000 mg/L	160.2	209C
Chlorophyll a	0.100 mg/L		1002G

Note: The nitrogen series (ammonia nitrogen, nitrite+nitrate nitrogen, and total Kjeldahl nitrogen) will be collected only during the months of April, May, and June.

Chlorophyll a analyses will be corrected for pheophytin, and conducted only during the months of April through October.

[1] APHA - *Standard Methods for the Examination of Water and Wastewater*

the boat motor and/or the anchor. Do NOT drop the anchor alongside of the station marker or tie the boat to the station marker.

2. Record the date, time, and weather information on the In-situ Data Form. Use the 24 hour military system for time (e.g., 3:00 pm is 15:00). Note any unusual conditions or problems in the comments section of the form, and print the sampler(s) name at the bottom of the form.

3. Secchi disk transparency readings are to be made during midday, without the use of sunglasses, from the shady side of the boat. The observer makes the reading by looking as close to the water as possible to minimize glare. The observer should be wearing a life vest. Lower the Secchi disk into the water until it can no longer be seen. Place a clothes pin on the line at the water's surface. Lower the Secchi disk another 6 to 8 inches, then raise it until it can just be seen through the water surface. Place another clothes pin on the line at the water's surface. Retrieve the Secchi disk and record the average of the two depths, noted by the clothes pins, in the Secchi depth section on the In-situ Data Form.

4. Measure dissolved oxygen (DO) and temperature (T) at three (3) foot increments from the surface to the lake bottom using the dissolved oxygen meter with temperature capability. Follow the manufacturer's instruction in operating the meter. It is a good idea to gently move the probe up and down approximately 1 inch during the measurement to ensure that there is a flow of water past the probe membrane. Record each pair of readings (DO and T) for each depth on the In-situ Data Form.

LAKE OF THE WOODS PHASE II MONITORING PROGRAM
IN-SITU DATA FORM

Sample Station: ______________ Date: ___ ___ ___
mm dd yy

Secchi Depth (in): ___ ___ . ___ Time: ___ ___ : ___ ___
(24 Hr)

Weather (Temp., Wind direction/speed, Precipitation, Cloud cover)

Depth (ft)	Temp (°C)	DO (mg/L)	pH	Water Sample Collected?
Surface				

Comments

Sampler:

Figure 20. In-situ data form for the in-lake samples.

5. Collect water samples from a depth of 1 foot below the surface, two feet below the top of the hypolimnion (if present), and from approximately 3 feet above the lake sediments. Be careful not to include any sediment in the bottom sample. It is a good idea to collect the lowest concentration samples first, e.g., collect the surface samples before the bottom samples.

   a. Thoroughly rinse the Van Dorn sampling bottle, several times, with lake water prior to collecting the samples. Lower the Van Dorn sampling bottle to the appropriate depth and close the bottle to collect the sample. Retrieve the Van Dorn on-board the boat, place on a stable surface, and open the vent port.

   b. If a preservative has been added to the sample containers provided by the analytical laboratory, do not rinse the containers. Total phosphorus (TP), ammonium nitrogen, nitrite-nitrate nitrogen, and total Kjeldahl nitrogen can be analyzed out of a single sample that has been preserved with H_2SO_4 to a pH of 2 or less. Fill the containers with water from the sampling bottle and replace the cap, excluding as much air as possible. These samples must be analyzed within seven (7) days following preservation, according to EPA methods.

   c. The dissolved reactive phosphorus samples should not be acidified, but must be field filtered, cooled, and analyzed within 24 hours of collection. The total suspended solids samples should not be acidified.

   d. The chlorophyll a (Chl a) samples should be collected, on a depth integrated basis, from the top six (6) feet of the water column. The samples should be collected with an appropriate water sampling bottle, pump, or tube collector. The samples must be filtered through a glass fiber filter immediately in the field, then the filter should be cooled (frozen) and stored in an opaque container until analyzed.

   e. Upon completion of the sample collection, check to make sure that all data forms have been completed and all samples labeled. The samples should be placed in the dark and cooled to 4°C. This can be accomplished by placing them in an ice chest with ice or coolant.

6. Record the lake level at the outlet structure.

6.6 METHODS FOR WATERSHED MONITORING

Lakes are products of their watersheds; therefore, the water quality of a lake reflects the conditions and management of it's watershed. Most lake restoration projects include a watershed component. In the case of Lake of the Woods, the watershed component addresses agricultural practices, and is geared toward reducing non-point source pollutant loadings to the lake. In the context of Phase II studies, the term "watershed monitoring" will include the collection and analysis of chemical and hydrological data, as well as watershed inventories and general condition surveys. For Lake of the Woods, watershed monitoring will include limited stream monitoring and watershed inventories.

6.6.1 Parameters

The critical parameters to be measured are:

- Temperature
- Dissolved oxygen
- Total suspended solids
- Total phosphorus
- Dissolved reactive phosphorus
- Nitrite+Nitrate nitrogen
- Ammonia nitrogen
- Total Kjeldahl nitrogen
- Streamflow rate.

The analytical methods and detection limits for these parameters are the same as those listed in Table 36. The nitrogen series (nitrite + nitrate nitrogen, ammonia nitrogen, and total Kjeldahl nitrogen) will be measured only during the months of April, May, and June.

6.6.2 Analytical Costs

Representative ranges of analytical costs presented in Table 37. Laboratories may offer a reduced cost

Table 37. Analytical costs for the Phase II monitoring program.

Parameter	Per Sample Cost
Total Phosphorus	\$15 - \$25
Dissolved Reactive Phosphorus	\$12 - \$16
Ammonia Nitrogen	\$12 - \$16
Nitrite+Nitrate Nitrogen	\$12 - \$15
Total Kjeldahl Nitrogen	\$18 - \$30
Total Suspended Solids	\$ 9 - \$12
Chlorophyll a	\$12 - \$25

for analyses of a quantity of samples. When contracting with a laboratory for analyses of the water samples, it is important to specify the number of samples collected per sampling period and the number of anticipated sampling periods. The recommended analytical methods and required detection limits should also be presented to the proposed contracting laboratory. Additionally, many commercial laboratories are not equipped to analyze for chlorophyll a. The Lake of the Woods Homeowner's Association may need to contract with a university (e.g., Purdue University, Indiana University, Ball State University, etc.) for these analyses.

6.6.3 Sampling Procedures

The following steps are to be followed at the two (2) watershed stations for every sampling event. The in-situ measurements (i.e., temperature and dissolved oxygen) will be entered on a Watershed Sample Collection Data Form (Figure 21).

1. Record the date, time, and weather information on the Data Form. Use the 24 hour military system for time, as previously described. Note any unusual conditions or problems associated with each site in the comments section of the form. Print the sampler(s) name at the bottom of the form.

2. Measure the dissolved oxygen (DO) and temperature (T) in the stream at the sample site. Try to avoid taking these measurements in stagnant water or swirling or eddying areas. The bottom sediments should not be disturbed when lowering the probe into the stream. Follow the manufacturer's instructions in operating the dissolved oxygen meter. Record each pair of readings (DO and T) for each sampling station on the Sample Collection Data Form.

3. Collect a grab sample from flowing stream water, avoiding areas of stagnant water or swirling or eddying areas. If possible, collect the sample without entering the flow. If it is necessary to enter the stream, try to avoid disturbing the bottom sediments. Samples should be collected upstream from where you are standing.

    a. If a preservative has been added to the sample containers provided by the laboratory, do not rinse the containers.

    b. If the sample containers do not contain a preservative, rinse the container by submerging it in the stream with the mouth pointed into the current. Fill the container and discard the rinse water by pouring it over the bottle cap while holding the cap downstream from the sample collection point. Repeat the rinse procedure two more times.

    c. To collect the grab sample, hold the container firmly, keeping your hands away from the mouth. Without disturbing the sediments, quickly submerge the container in the flow with the mouth pointed into the current and fill it completely. Remove the container from the stream, checking to see that the water level is very near to the top of the container. Replace the cap, excluding as much air as possible. Attach a completed sample label to the sample container.

LAKE OF THE WOODS PHASE II MONITORING PROGRAM
WATERSHED SAMPLE COLLECTION DATA FORM

Date: ____ ____ ____
mm dd yy

Weather (Temp., Wind direction/speed, Precipitation, Cloud cover)

Station #	Temp (°C)	DO (mg/L)	Time Collected	Comments
2				
3				
duplicate				
blank				

Comments

Sampler:

Figure 21. Watershed sample collection data form.

d. Total phosphorus, ammonium nitrogen, nitrite-nitrate nitrogen, and total Kjeldahl nitrogen can be analyzed out of a single sample that has been preserved with H_2SO_4 to a pH of 2 or less. These samples must be analyzed within seven (7) days following preservation, according to EPA methods. The dissolved reactive phosphorus samples should not be acidified, but must be field filtered, cooled, and analyzed within 24 hours of collection. The total suspended solids samples should not be acidified.

e. Upon completion of the sample collection, check to make sure that all data forms have been completed and all samples labelled. Place the samples in the dark and cool to 4°C. This can be accomplished by placing them in an ice chest with ice or coolant.

4. Measure stream discharge (i.e., streamflow) at each sampling station. Discharge is defined as the volume rate of flow of water, and is usually measured in cubic feet per second past a specific point in the stream. Streamflow measurements can be accomplished continuously or instantaneously. We would recommend that the Lake of the Woods Homeowners Association work with the Marshall County Surveyor to develop a stage-discharge relationship at these two sampling stations. Once this relationship is developed, flow rate determinations can be made by simple stage readings. Instantaneous flow measurements should be made periodically to verify the stability of the stage-discharge relationship, with the relationship modified as necessary. Methods for actual discharge measurement should follow established USGS procedures, as outlined in Buchanan and Somers (1980).

6.6.4 Watershed Inventory

The Clean Lakes Phase II monitoring plan should have a component that describes watershed conditions after construction is completed. The level of complexity necessary is dependent on the land uses and the actions taken to improve watershed conditions.

During the Phase II implementation (i.e., BMP installation), a periodic inspection program should be instituted to document the installation of practices as specified in the project design, and to ensure that associated interim control measures (i.e., short-term erosion control practices) are being used. Additionally, the watershed should undergo a periodic inspection during critical time periods (e.g., late winter and late spring) to check for new problems that might be developing, to verify earlier surveys, and to identify previously unobserved problems. The inspections should be documented by observer notes and references to a map of the watershed. A typical checklist for these inspections would include:

- Are the watershed management practices being installed according to design?
- Are adequate controls in place to prevent unnecessary erosion or loss of nutrients at implementation sites?
- Are agricultural practices being improved according to design?

- Are there any new construction sites that were not anticipated and, if so, are adequate control measures in place?
- Have there been any new building permit applications or zoning changes that are potentially detrimental to project success?

After the Phase II implementation is completed, watershed conditions should be immediately inventoried to establish a baseline for future evaluations. This survey will also serve as the model for future routine inspections.

The watershed inventory requires the delineation of watershed boundaries and land uses on a map. A 7.5 minute topographic map is commonly used and considered sufficient. Land uses in the watershed should be broken into the basic categories identified in Table 38 and characterized as a percentage of the total watershed size. Level I information should always be provided. Level II or higher information should be required to document uses having high contamination potential (i.e., point sources, confined feedlots, land under development). Section 4.2.4 of this report describes the results of the land use survey component of this report. This information may be used as a template, and updated by office reviews and field inspection.

Table 38. Basic land use descriptions (from Wedepohl, et.al. 1990).

LEVEL I	LEVEL II
1. Urban or built-up land	11. Low density residential 12. Medium density residential 13. High density residential 14. Commercial and Industrial 15. Land under development 16. Other urban or intensively used land
2. Agricultural land	21. Row crops 22. Non-rowcrops 23. Pasture 24. Confined feeding areas 25. Mixed agriculture 26. Other agricultural land
3. Forest	31. Deciduous forest 32. Evergreen forest 33. Mixed forest
4. Water	41. Streams and canals 42. Lakes and reservoirs 43. Forested wetland 44. Nonforested wetland

6.7 METHODS FOR IN-LAKE MONITORING DURING AND AFTER ALUM APPLICATION

This portion of the Phase II monitoring plan applies specifically to the recommended in-lake restoration technique for phosphorus precipitation/inactivation via the use of alum. Additional information pertaining to monitoring during this lake restoration technique can be found in Wedepohl, et. al. (1990).

6.7.1 Monitoring During Alum Treatment

The critical parameters to be measured during the alum application are:

- pH
- alkalinity
- dissolved aluminum
- dissolved oxygen
- temperature
- total phosphorus
- dissolved reactive phosphorus.

Analyses for these parameters should be conducted using U.S. EPA approved methodologies.

The utility of measuring phosphorus depends on the length of time required for treatment. For example, if the alum application takes less than two weeks to complete, it is unlikely that the results of a phosphorus analysis will be available in time to serve any useful purpose during the treatment period. However, if the application time is longer than two weeks, phosphorus should be included as a measured parameter.

The sampling location should be at the deepest part of the lake. Dissolved oxygen and temperature measurements should be made at three (3) foot intervals from the surface to the bottom. Samples should be collected at six (6) foot intervals from just below the surface to the lake bottom. Table 39, from Wedepohl, et.al. (1990), gives the recommended specifications for in-lake monitoring during an alum treatment.

6.7.2 Monitoring Following Alum Treatment

The success of an alum treatment is defined by decreased algal standing crop (commonly measured by Chla) and a decreased phosphorus concentration following treatment. Alkalinity and pH are necessary chemical measurements that should be continued following application of alum. These two measurements are taken to detect any adverse environmental conditions that can occur in association with an alum treatment. If adverse environmental lake conditions (e.g., low DO) develop during the post-project monitoring, these data will be necessary to determine the cause of the event. Temperature and DO should also be measured. This information is needed to determine the occurrence of anoxia in the hypolimnion,

Table 39. In-lake sampling design during an alum treatment.

A. Water Chemistry

1. Analytical Determinations and Sampling Procedures
   (a) If the alum application takes less than two weeks, measure pH and alkalinity.
   (b) If the alum application takes longer than two weeks, measure pH, alkalinity, dissolved aluminum, total phosphorus, and dissolved reactive phosphorus.

2. Frequency and Duration
   (a) If the alum application takes less than two weeks, sample daily.
   (b) If the alum application takes longer than two weeks, samples should be collected as follows:
   - pH: sample daily
   - alkalinity: sample daily
   - dissolved aluminum: sample once per week and
   - total phosphorus and dissolved reactive phosphorus: once every two weeks.

B. Dissolved Oxygen and Temperature

1. Frequency and Duration
   Measurements should be made at weekly intervals.

the length of time the lake remains thermally stratified, and the timing of complete lake mixing. Table 40, from Wedepohl, et.al. (1990), gives the recommended specifications for in-lake monitoring after an alum treatment.

Documenting changes to macrophyte communities is also useful in that the improved water clarity associated with alum treatment can stimulate undesirable macrophyte growth in shallow areas of the lake. The level of effort required for completion of macrophyte surveys varies greatly. The surveys associated with Phase II projects must be quantitative enough to allow comparison between surveys. Species composition, distribution, abundance, and maximum depth of growth during the growing season can be documented by visual observations. Locate major community types (i.e., emergents, floating-leaved, and submergents), then determine species composition and abundance of each community. The information is best presented on a hydrographic lake map that illustrates community distribution, with a species list and appropriate abundance symbol for each location. The boundaries of single species stands within the more general community type should also be noted. The plants should be identified to species level using a regional identification manual such as Fassett (1969) or Muencher (1964).

6.8 FIELD QUALITY CONTROL SAMPLES

Every sampling event should include field quality control check samples. The types of quality control samples recommended for the Lake of the Woods monitoring program are field duplicates and field blanks. One field duplicate and one field blank sample should be collected during each sampling event and sent to the analytical laboratory. A separate chlorophyll a field duplicate should be collected from

Table 40. In-lake monitoring design following alum treatment.

A. Water Chemistry

1. Analytical Determinations and Sampling Procedures
   Water samples should be analyzed for alkalinity, pH, total phosphorus, dissolved reactive phosphorus, and dissolved aluminum. Note: dissolved aluminum may be discontinued if two consecutive samples are below 50 $\mu g/L$.

2. Frequency and Duration
   Samples should be collected at a minimum of monthly intervals for a period of two years following treatment.

B. Dissolved Oxygen and Temperature

1. Frequency and Duration
   Same as for water chemistry.

C. Secchi Disk Transparency

1. Frequency and Duration
   Measurements should be made at a minimum of monthly intervals during the growing season (May through October) for a period of two years following treatment.

D. Chlorophyll a (corrected for pheophytin)

1. Depth Distribution
   A subsample should be obtained from an integrated sample representing a water column equal to 0-6 feet from the surface.

2. Frequency and Duration
   Samples should be collected at a minimum of monthly intervals during the growing season (May through October) for a period of two years following treatment.

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the in-lake station.

1. Field Duplicates. A field duplicate is a sample taken to determine the variability in the sampling procedure and the source sampled. This sample may be collected from either the in-lake station or the watershed stations. It is important that the site where the duplicate sample is collected be chosen randomly and not always at the site where it is easiest to collect. Collect the field duplicate immediately after the regular sample is collected. The duplicate should be collected in the same manner as the regular sample, but using a second grab sample. Attach a completed label to the sample container.

2. Field Blanks. A field blank is a sample of reagent grade deionized water that is processed through the sampling equipment (e.g., the horizontal Van Dorn sampling bottle or the bottles used to collect the stream samples) in the same manner as the actual water sample. This is done to determine if field

equipment cleaning procedures are adequate. Ideally, no contaminants will be detected in the field blank. Field blanks may be collected at either lake or stream stations. The location should be selected randomly, as with the field duplicates.

To collect a field blank at the lake station, rinse the Van Dorn sampling bottle three times with deionized water, then fill the Van Dorn with deionized water. Pour the water from the sampling bottle into the sample container, filling the container. Replace the cap, excluding as much air as possible, and attach a completed label to the container.

To collect a field blank at a stream station, fill the grab sample bottle with deionized water such that the water level is very near to the top of the container. Replace the cap, excluding as much air as possible. Attach a completed sample label to the sample container.

6.9 DATA MANAGEMENT

A single individual, or small group of individuals, should be responsible for all data collection and records maintenance to ensure that the monitoring is conducted reliably and consistently. Consistency of technique and analytical methods is essential to minimize random variability in the data and maximize the value of the collected information in detecting changes over time.

Standardized data forms should be developed and used for all field measurements and sample collection. The forms should be simple, but complete, and as easy to use in the field as possible. Both the in-situ data, and the results from the analytical laboratory should be entered into a PC-based database. There are numerous software packages available that provide the necessary features for ease of maintenance, statistical analyses, and graphics.

6.9.1 Data Interpretation

The data generated by this program will provide a good characterization of Lake of the Woods. There are some simple methods for presenting the data that will allow local lake managers to utilize the data and draw some basic conclusions.

Graphic plots of the water quality and sediment data should be maintained as a basic interpretive tool. Water quality time-series data plots can be used to visually detect seasonal trends, long-term trends, and differences in extreme values between years. Fitting a simple linear regression through time-series data will often allow the detection of a long-term increase or decrease in a measured parameter (i.e., Secchi disk transparency or depth to sediment). Such a trend would be revealed by a regression slope that is statistically significantly different from zero.

Water quality parameters may be evaluated in terms of annual statistics. A simple example would be the examination of the average annual Secchi disk transparency along with the range of transparencies observed during the year. A trend of decreasing annual means and minimum transparencies would suggest that either suspended sediment or algae concentrations are increasing. Additionally, the Carlson trophic state index (TSI) could be applied to the routine water quality data collected on the lake. A more representative trophic state assessment could be obtained by examination of the TSI values observed over a period of time. A good limnological text, such as Wetzel (1983) will provide more detailed interpretive guidance than can be provided within the scope of this investigation.

SECTION 7. SUMMARY AND RECOMMENDATIONS

This section of the report summarizes the results of the lake and watershed survey, modeling of sediment and nutrient transport in the watershed, annualized phosphorus modeling, and bathymetry. Recommendations that follow are based on these results, however the reader is urged to view this report in its entirety, and not draw conclusions based on the following brief section.

7.1 SUMMARY

- The primary factor that has led to deteriorating water quality in Lake of the Woods is nutrient inputs from the watershed. The results of the AGNPS model showed that all of the areas that were identified as contributing disproportionately greater amounts of sediments and/or nutrients during a modeled storm event are used for row crop agriculture.

- The concentration of nitrogen in the bottom sediments of the lake was notably high. No specific source of the nitrogen was identified, but this suggests a long period of over-application of nitrogen fertilizers to crop lands.

- The in-lake phosphorus concentration near the lake bottom was also very high, and points to the lake sediments as an important source of phosphorus. The nitrogen to phosphorus ratio for the lake water samples clearly showed that phosphorus is the limiting nutrient.

- Bacteria samples from the lake and major tributaries (Martin and Walt Kimball Ditches) were all well within acceptable limits established by IDEM.

- A BonHomme Trophic State Index calculated for the lake, based on samples collected in September, 1990, was 50. This places the lake at the upper boundary of Trophic Class II (values 26-50). Class II lakes are moderately eutrophic, and support frequent algal blooms during the summer months. Trophic Class III (values 51-75), contains the most eutrophic lakes in the State. A second measure of trophic state, the Carlson Trophic Index, was also calculated. The results of this index firmly placed the lake in the eutrophic category.

- The quantity of phosphorus reaching the lake from lakeshore septic systems was calculated at 211 kg (466 pounds) per year. This figure corresponds closely to the 225 kg phosphorus reported in the 1982 Diagnostic Feasibility Study. However, the percentage of total external phosphorus loading contributed by septic systems was 5%, a figure much smaller than the 21% reported in the 1982 study. Runoff from the watershed supplied 92.5% of the phosphorus on an annual basis, and atmospheric inputs the remaining 2.5%.

- A bathymetric survey of the lake was conducted, and the results were compared to a similar survey done in 1955 by IDNR. There was a small decrease in volume over the 35 year period (three percent). Little change was seen in depths ranging from zero to 30 feet; however, comparison of the deepest contour intervals show a greater loss of volume on a percentage basis. The sedimentation rate for the lake, based on the overall difference in volume, was 0.17 inches per year over the 35 year period. This is a moderate value, and is not indicative of a "sedimentation problem" for Lake of the Woods.

7.2 RECOMMENDATIONS

One of the objectives of this study was to update and add to the recommendations contained in the 1982 Clean Lakes Feasibility Study (Senft and Roberts, 1982). The primary recommendation of the 1982 study was to implement a septic sewer ? system for lakeshore residences. This has not been implemented but is currently under serious consideration. The results mentioned in Section 7.1 and Section 4.2.6 concerning septic system phosphorus inputs support the results of the 1982 study in terms of the quantity of phosphorus reaching the lake. However, the calculated proportion of septic system phosphorus contributions to the total annual phosphorus loading to Lake of the Woods was approximately five times less than that reported in the 1982 study (5% versus 21%). Despite this change in terms of the relative contribution of the septic systems, the total reduction of phosphorus and bacteria from residential septic systems that would result from a sewer system would obviously benefit lake water quality. The soils that contain the majority of the drain fields are classified "severe" in the Marshall County Soil Survey. These are the worst possible sites for drainfield locations, and quickly become clogged due to saturated conditions and poor drainage. Values used for calculation of phosphorus retention in lakeshore drain fields were zero, i.e., no retention. Drain fields in excess of 20 years old in soils surrounding the majority of the lakeshore retain little or no phosphorus. The only retention of residential phosphorus therefore occurs in the septic tank itself.

The 1982 study also recommended that the Lake of the Woods Property Owners Association purchase a weed harvester. This was done, and an ongoing weed harvesting program has been implemented. The current study did not collect data that could be used to evaluate the success of these efforts. As a general recommendation, the objectives of harvesting should be to maintain open water in selected areas where macrophyte growth prevents swimming or boating. Lakewide efforts to reduce or eliminate aquatic plants are likely to reduce important fish habitat, and may increase the frequency of algal blooms.

The primary recommendations of this study are consistent with those recommended in 1982: improve water quality in Lake of the Woods through watershed best management practices. In addition, a major recommendation of the current study is to treat the lake with alum (see section 5.3.1) as a one time measure to remove phosphorus from the water column, and, more importantly, to inactivate phosphorus in the lake sediments. A sedimentation basin and/or a constructed wetland were originally considered; however, the results of the watershed survey and lake sedimentation rate calculation do not support the need for a sedimentation basin at this time. A basin to the northwest of the lake that would accommodate storm runoff from both Martin and Walt Kimble Ditches was a consideration. Both tributaries enter the lake within the 25 acre area defined as cell #159 on Figure 10, the AGNPS cell layout. However, soils in this area are largely composed of Houghton muck, a deep and unconsolidated soil that is difficult to work with and very unstable. In many cases, this soil will not support the weight of vehicles and heavy equipment, or the dike that would be necessary to contain the sediments. In addition, it was felt that the modeling results, which showed the greatest throughput, or transport of sediment in this area of the watershed, were largely due to the lack of depositional areas in the upper watershed, particularly the western section of the Martin Ditch sub-basin. Given that this situation has not resulted in significant sedimentation within the lake, there is a high probability that conservation tillage and other BMPs, such as filter strips and critical area planting, will significantly reduce downstream sedimentation. Sediment basins and traps are costly and require at least annual maintenance to remove accumulated material. Studies have shown that sedimentation basins themselves can actually increase the phosphorus content of a tributary if they are not adequately maintained.

Constructed wetlands are preferable to a sediment basin or trap because of the multiple benefits they provide and because of greater efficiency in removing soluble nutrients. While this was considered a more effective and beneficial treatment than a sediment basin, the same factors cited with respect to the sediment basin prevented this from being a practical and viable approach to reducing nutrient inputs from the watershed. Moreover, a concerted watershed approach, involving widespread efforts to reduce the nutrient content of runoff, would be a much more efficient and cost effective strategy. In order of priority, the overall recommendations based on the results of this project are outlined below.

- Continue to implement BMPs on agricultural lands in the watershed. Research has shown that no-till farming and buffer strips along stream banks are extremely effective in improving surface water quality. The Marshall County SWCD and SCS have made significant progress in this area, and will take the lead in providing educational and technical assistance to land users in the watershed.

- Theoretical Financial assistance for upland BMPs has been recently made available through creation of the Lake Enhancement Program's Lake Watershed Treatment Program. The Lake of the Woods Homeowners Association should pursue funding for upland BMPs through this program. Applications are made by the local SWCD for a particular watershed. Control of nutrient inputs to the lake should be the primary goal of upland BMPs implemented under this program for the Lake of the Woods watershed. Soil testing prior to fertilizer application, proper manure handling and storage, and effective animal waste operations should be the key components of a watershed treatment program.

- Apply aluminum sulfate (alum) as a one time treatment to inactivate phosphorus in the lake sediments and reduce phosphorus levels in the water column.

- Implement a volunteer monitoring program to track the progress of upland BMPs and lake restoration activities.

- The Lake of the Woods Homeowners Association should become familiar with the U.S. Fish and Wildlife's Wetland Restoration Program. This program restores drained wetlands at no cost to the landowner, and has been very successful in Indiana. Wetlands are an extremely valuable resource in the watershed, providing excellent wildlife habitat and reducing non-point source pollutants and runoff. Landowners in the watershed, particularly those with property containing hydric soils, are strongly advised to contact Jerry Pearson and the U.S. Fish and Wildlife Service regarding wetland restoration.

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APPENDIX A

REQUIREMENTS FOR ENVIRONMENTAL EVALUATION
U.S. EPA CLEAN LAKES PROGRAM

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REQUIREMENTS FOR ENVIRONMENTAL EVALUATION
U.S. EPA CLEAN LAKES PROGRAM
(Federal Register, Vol. 45, No. 25, February 5, 1980, p. 7799)

1. *Will the proposed project displace any people?*

No management recommendations or proposed restoration measures will require or necessitate the displacement of any persons.

2. *Will the proposed project deface existing residences or residential areas? What mitigative actions such as landscaping, screening or buffer zones have been considered? Are they included?*

No management recommendations or proposed restoration measures will deface any existing residences or residential areas. Mitigative actions involving screening, landscaping and/or buffer zones are not necessary.

3. *Will the proposed project be likely to lead to a change in established land use patterns, such as increased development pressure near the lake? To what extent and how will this change be controlled through land use planning, zoning, or through other methods?*

The management recommendations listed in Section 7.2 of this report are not likely to lead to a change in established land use patterns or development near the lake. Implementation of watershed BMPs may exert a positive influence on land use within the agricultural watershed via the planting of streamside buffer strips and other agricultural and urban nutrient and erosion control practices.

4. *Will the proposed project adversely affect a significant amount of prime agricultural land or agricultural operations on such land?*

The management recommendations (both in-lake and watershed strategies) will not adversely affect any prime agricultural land, and should have no adverse affect on agricultural operations within the watershed. The implementation of BMPs may exert a positive influence on agricultural operations within the watershed via the implementation of nutrient and erosion control measures.

5. *Will the proposed project result in a significant adverse effect on parkland, other public land, or lands of recognized scenic value?*

No management recommendations will result in a significant adverse effect on parkland, other public land, or lands of recognized scenic value.

6. *Has the State Historical Society or State Historical Preservation Officer been contacted? Has he responded, and if so, what was the nature of that response? Will the proposed project result in a significant adverse effect on lands or structures of historic, architectural, archeological or cultural value?*

The State Historical Society or State Preservation Officer has not been contacted. It is anticipated that the proposed management recommendations will not have any adverse effect on lands or structures of historic, architectural, archeological, or cultural value.

7. *Will the proposed project lead to a significant long-range increase in energy demands?*

No management recommendations will lead to a significant long-range increase in energy demand.

8. *Will the proposed project result in significant and long range adverse changes in ambient air quality or noise levels? Short term?*

No management recommendations will result in significant and long range adverse changes in ambient air quality or noise levels. Short term changes in air quality and noise levels may result from implementation of management recommendations and restoration measures. All equipment used to implement the recommendations will be equipped with appropriate emissions and noise controls, Dust control measures will be implemented as needed.

9. *If the proposed project involves the use of in-lake chemical treatment, what long and short term adverse effects can be expected from that treatment? How will the project recipient mitigate these effects?*

The long and short term adverse effects that can be anticipated from the use of aluminum sulfate (alum) for phosphorus precipitation and inactivation are outlined in Section 5.3.1 of this report. These adverse effects relate chiefly to aluminum toxicity that occurs when the alkalinity of the lake is insufficient to buffer the effects of the alum. Included in Section 6.7 are methods for in-lake monitoring during and after an alum application to monitor the water column pH and alkalinity (buffering capacity) during treatment, as well as to determine the overall effectiveness of the application.

10. *Does the proposal contain all the information that EPA requires in order to determine whether the project complies with Executive Order 11988 on floodplains? Is the proposed project located in a floodplain? If so, will the project involve construction of structures in the floodplain? What steps will be taken to reduce the possible effects of flood damage to the project?*

The proposed in-lake restoration will occur within the floodplain of Lake of the Woods, but will not involve the construction of any structures or facilities in the floodplain. The potential for flood damage to the proposed project will not be enhanced, nor minimized, by implementation of the proposed management recommendations (Section 7.2).

11. *If the project involves physically modifying the lake shore or its bed or its watershed, by dredging, for example, what steps will be taken to minimize any immediate and long term adverse effects of such activities? When dredging is employed, where will the dredged material be deposited, what can be expected and what measures will the recipient employ to minimize any significant adverse impacts from its deposition?*

No recommendations have been made to dredge Lake of the Woods, or physically modify the lake shore or watershed.

12. *Does the project proposal contain all information that EPA requires in order to determine whether the project complies with Executive Order 11990 on wetlands? Will the proposed project have a significant adverse effect on fish and wildlife, or on wetlands or any other wildlife habitat, especially those of endangered species? How significant is this impact in relation to the local or regional critical habitat needs? Have actions to mitigate habitat destruction been incorporated into the project? Has the recipient properly consulted with appropriate State and Federal fish, game and wildlife agencies and with the U.S. Fish and Wildlife Service? What were their replies?*

The management recommendations contained in this report will not have any significant adverse effect on fish and wildlife, endangered species, or on wetlands or any other wildlife habitat.

13. *Describe any feasible alternatives to the proposed project in terms of environmental impacts, commitment of resources, public interest and costs and why they were not proposed?*

All alternative sediment and nutrient control strategies and in-lake restoration measures for Lake of the Woods and its' watershed are noted in Section 5 of this report. Section 7.2 lists the specific management recommendations that resulted from this study of Lake of the Woods.